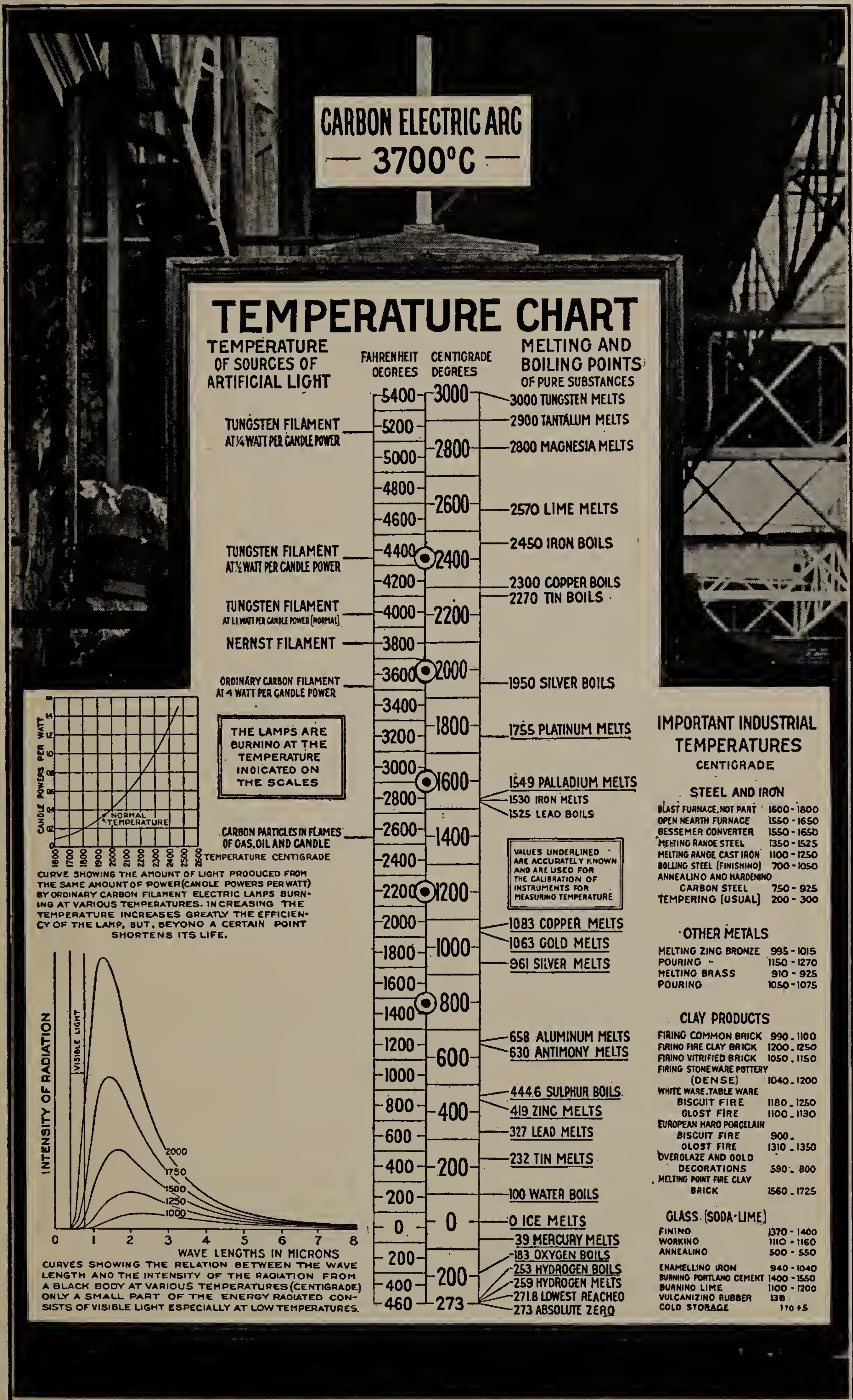
A PRACTICAL PHYSICS MANUAL

AHRENS, HARLEY, AND BURNS



Courtesy of U. S. Bureau of Standards. *Frontispiece*

Temperature chart exhibited at the Panama-Pacific Exposition. The small circles were incandescent lamps at the respective temperatures.

A PRACTICAL PHYSICS MANUAL

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WITH 133 ILLUSTRATIONS

PHILADELPHIA
P. BLAKISTON'S SON & CO.
1012 WALNUT STREET

PREFACE

While the new movement in the teaching of physics—the study of the physics of daily life—is the keynote of the recent text-books, yet the laboratory manuals still adhere to the old method, leaving the presentation of material from everyday life to the text-book alone. It is our belief that the manual as well as the text-book should be based on practical physics. This has been our viewpoint in the development of the manual herewith presented. The method is to give, first, a fundamental experiment in which the principle under consideration is made clear to the student, then to follow this with an experiment or a number of experiments on the practical applications of that principle. It has been our purpose to simplify these fundamental experiments, omitting useless manipulation and utilizing the time thus saved for experiments on practical applications. With manipulation thus reduced to a minimum, the pupil can complete a larger number of experiments in one year than is generally thought possible. Needlessly complicated manipulation holds back the pupil, and is inefficient.

In the selection of "applications," the authors have recognized the divergent interests of boys and girls. To the former, engineering problems have a fascination; to the latter, fundamental experiments are interesting, generally speaking, only so far as they serve to explain household applications. We feel no responsibility for presenting proofs of the differences between boys and girls as regards their interest in topics from physics, our duty being rather to recognize these differences as already established and to provide experiments suited to these diverse needs. In the undertaking, we recognize the fact that we are pioneers subject to the mistakes in judgment of pioneers

in any new field. Of one thing we are certain—the field lies where we have traveled. Whether the path we have traveled will become well-worn remains to be seen; the route, however, has been carefully, and, we believe, wisely chosen.

In explanation of our plan, we have divided our index of experiments into three groups as follows:

The first, known as the General Course, comprises the entire list, all fundamental experiments (56 in number) being printed in bold-faced type, and forming by themselves a group sufficiently large to prepare students for any college. The instructor may then select from the rest of the list such as suit the needs of his school or equipment.

The second group is known as the Technical Course. It consists of the fundamental experiments and in addition others specially designed for boys preparing for the technical trades or for engineering.

The third group, known as Household Physics, is designed for girls. It includes almost all the fundamental experiments and in addition a great many of household application for the benefit of that great majority of girls who take physics, not for technical purposes, but from a desire to understand household problems. In the selection of these experiments we have been fortunate in having the advice of teachers of Domestic Science who have had long experience with girls and girls' needs—Miss Grace E. Moore of the Flower Technical High School for Girls, Mrs. Stella M. Hubbell of the Englewood High School, and Miss Ina R. Campbell of the Hyde Park High School—all of Chicago. To them we are grateful for valuable assistance.

Walter R. Ahrens.
Theodore L. Harley.
Elmer E. Burns.

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PRACTICAL PHYSICS MANUAL

EXPERIMENT I

THE VALUE OF π AND THE VOLUME OF A CYLINDER

What does the value of π express?

What to do:

(*a*) Secure a cylinder and by means of your ruler, measure its length very carefully. Take measurements in three or four different places and take the average of your results as the correct value. Now lay the cylinder on its side and on top of your ruler. Put a pencil mark on the end at the circumference. Place the cylinder so that this mark is in contact with one of the divisions on the ruler. Make note of which one this is. Now roll the cylinder along until this mark again comes into contact with the ruler. The distance between the two positions is the circumference of the cylinder. Make two or three trials to be sure you have made no mistakes.

(*b*) Repeat these measurements using the metric units in place of the English.

(*c*) Measure the diameter of one end of the cylinder. Divide the circumference which you found in paragraph (*a*) by the diameter. This value is known as Pi or π. The theoretical value is 3.1416. Does your result differ from this value? If it does, why does it?

(*d*) From your results and the following formula calcu-

late the volume of the cylinder in both the English and metric units.

$$\text{Volume} = \text{area of base} \times \text{height} = \frac{\pi D^2 H}{4}$$

In which D is the diameter and H is the height or length. Record your results in the following form:

	English	Metric
Length or height		
Diameter		
Circumference		
Circumference ÷ diameter		
Volume		

(*e*) Divide the length of the cylinder in centimeters by the length in inches. What does this value represent?

Materials Required.—English-metric ruler and a cylinder of about 200 c.c. volume.

EXPERIMENT 2

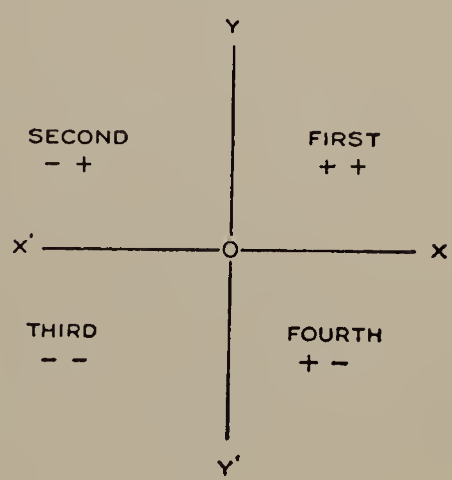
CURVE PLOTTING

Can you see any real value or advantage in graphs or curves?

What to do:

(*a*) A "graph" or "curve" is a pencil representation of the relationship existing between two quantities whose values are variables. The method is called the "Rectangular Coördinate Method."

Two lines $X'X$ and YY' are drawn so as to cross or intersect each other at right angles. $X'X$ is called the axis of abscissas and YY' is called the axis of ordinates. Their intersection is called the origin and is designated by the letter O. All points are referred to the origin. Abscissas are either positive or negative according as they are laid off to the right or left of the Y-axis. Ordinates are positive or negative according as they are laid off above or below the X-axis. In plotting curves the proper method is to give values to X and solve for the value of Y. All results should be put in tabular form. In plotting curves select a value for each square on the cross-section paper so that you will be able to get the smallest value and the largest value of X and Y on the paper. The scales for X and Y do not have to be the



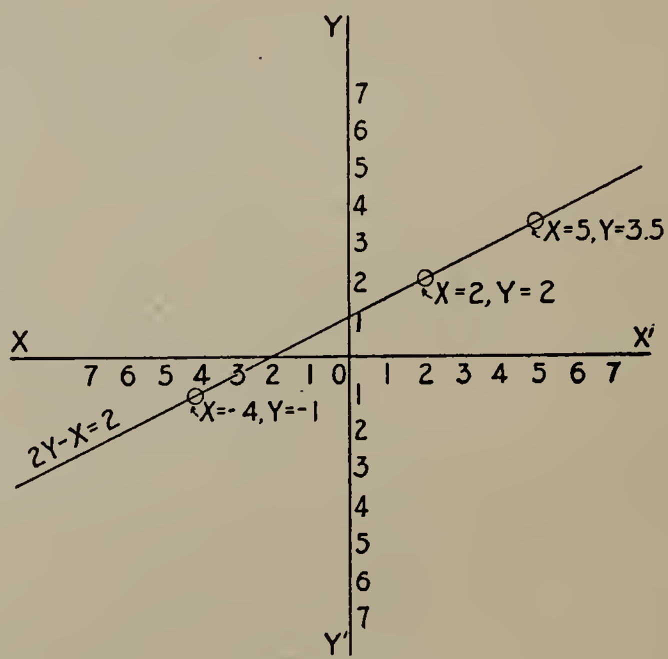
same. After you have located all the points, connect them by means of a smooth line. Do not have any jogs in it. If the points are so scattered that they cannot be easily connected, draw a curve which approximates all of them but does not pass through them.

(*b*) Using the above information plot curves for the following equations:

$2y - x = 2$	$x^2 - 8x + 14 = y$	
$4x - y = 10$	$x^2 - 8x + 16 = y$	$x^2 + y^2 = 36$
$2x + 3y = 6$	$x^2 - 8x + 20 = y$	

For example, taking the equation $2y - x = 2$ we get the following values for x and y. Then using the values just determined we locate the points as shown in the sketch.

x	y
4	3.0
3	2.5
2	2.0
1	1.5
0	1.0
−1	.5
−2	0
−3	−.5
−4	−1.0



Between what values can graphs be plotted?

Where would you suggest to use them?

Materials Required.—Equations, a good sharp pencil, and some cross-section paper.

EXPERIMENT 3

FUNCTIONS OF ANGLES

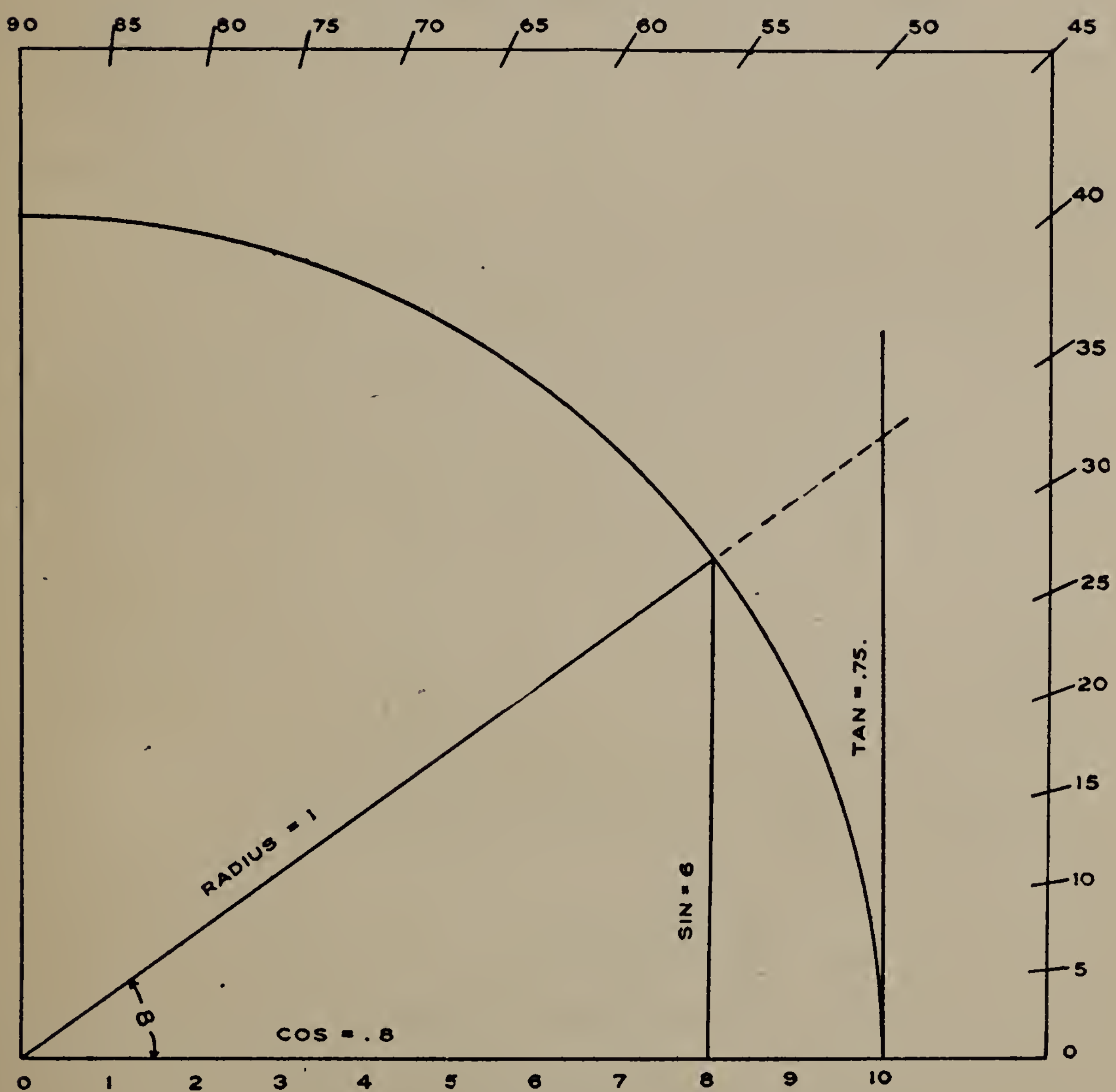


FIG. I.

What do we mean by the *functions* of an angle?

What to do:

(*a*) The radius is the unit for the measurement of all functions. Take a piece of cross-section paper. Draw

a vertical line two squares from the left-hand edge. Draw a horizontal line two squares from the bottom. These two lines are your axes.

(*b*) Now with your compass draw a quadrant whose radius is ten squares long. Divide this arc of 90° into divisions of 5° each. Project these divisions to the sides of a square which is two squares larger than the arc, as is shown in the drawing. Draw a tangent to the arc.

(*c*) Consider the radius of the arc as unity. The projection of any angle (*a*) on the vertical axis is a measure of the sine of that angle. The projection of the angle on the horizontal axis is a measure of the cosine. The tangent of the angle is the vertical distance from the point of intersection of the line tangent to the circle and the radius extended.

(*d*) By means of the chart you have just constructed measure the relative values of the sine, cosine, and tangent for every 5° angle and record your results in tabular form.

(*e*) From the right triangle we have:

$$\text{Altitude} \div \text{Hypotenuse} = \text{Sine.}$$
$$\text{Base} \div \text{Hypotenuse} = \text{Cosine.}$$
$$\text{Altitude} \div \text{Base} = \text{Tangent.}$$
$$\overline{\text{Altitude}}^2 + \overline{\text{Base}}^2 = \overline{\text{Radius}}^2 = \overline{\text{Hypotenuse}}^2.$$

(*f*) Knowing these relations determine the values of the following:

Angle	$\sin^2 + \cos^2 = R^2$	$\sin \div \cos = \tan$
0		
15		
30		
45		
60		
75		
90		

Materials Required.—Sheet of cross-section paper; a set of drawing instruments, or compass and ruler.

EXPERIMENT 4

THE VERNIER CALIPER

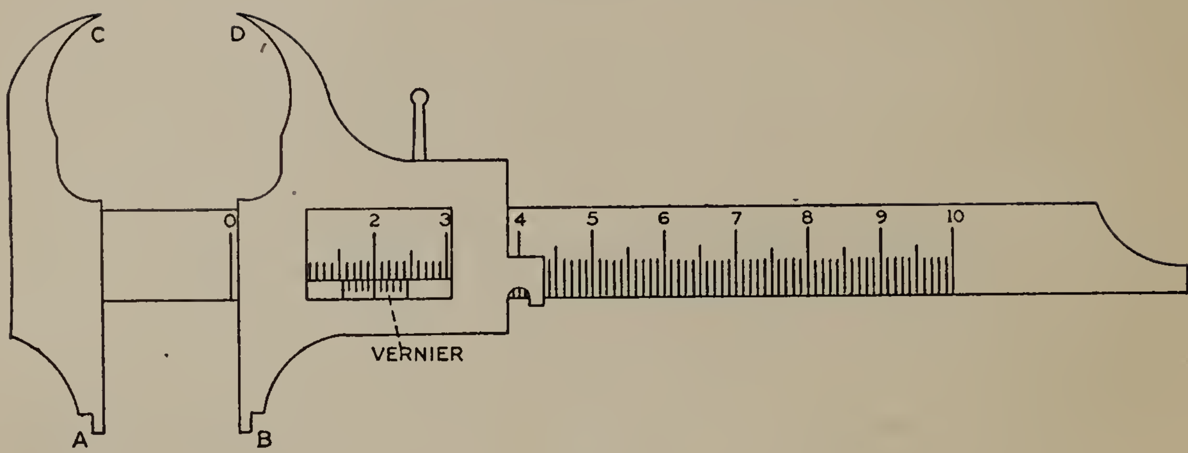


FIG. 2.

How can accurate measurements, say to tenths of a millimeter, be made?

What to do:

(*a*) Observe the sliding scale called a vernier (Fig. 2). Have the jaws of the caliper closed so that the zero line, the first mark on the scale of the vernier, coincides with the zero line of the fixed scale, that is, so that the two zero lines appear to form one straight line. Now note how many divisions or spaces there are in the vernier scale. The vernier should have ten spaces or scale divisions which correspond to nine spaces on the fixed scale. Count them. How many millimeters in length is the vernier scale? To answer this question count the number of millimeters on the fixed scale which equals the length of the vernier scale. The vernier scale should be 9 mm. in length. Now if the ten divisions of the vernier when taken together are 9 mm. in length, how long is one division of the vernier? How much less is it than 1 mm.?

Then, when the zero lines coincide, how far is line *one* on the vernier from line *one* on the fixed scale? By *line one* we mean the first line to the right of the zero line, that is, the second mark on the scale. How far is line *two* of the vernier from line *two* of the fixed scale? Line *three* from line *three*? Which lines would coincide if the jaws were opened $1/10$ mm.? Which lines if $3/10$ mm.? If $5/10$ mm.? If $7/10$ mm.? How then can you measure a fraction of a millimeter in tenths?

(*b*) Set the vernier so that the jaws are opened 1 mm. The zero line of the vernier now coincides with line one of the fixed scale. How far is line *one* of the vernier from line *two* of the fixed scale? If the jaws were opened 1.1 mm., where would line one of the vernier be? If the jaws were opened 1.2 mm. where would line two of the vernier be? If the jaws were opened 1.6 mm., which line of the vernier would coincide with a line of the fixed scale? How can you tell how many tenths are to be added to the whole number of millimeters?

Set the jaws so they are 2 mm. apart. Set them 2.1 mm. apart; 2.2 mm.; 2.7 mm.

(*c*) Measure the diameter of a wire, setting the vernier so that the jaws grip the wire just tight enough to hold it. Show the vernier, thus set, to the instructor and tell him what you find to be the diameter of the wire. Repeat with other objects such as wires of different diameters, metal spheres, brass tubes, etc., until you have no difficulty in reading the vernier.

(*d*) In the same way study a vernier for measuring fractions of an inch. Find the length of one division of the vernier. What is the difference between this length and the smallest division of the fixed scale? This difference is called the *least count*. Measure a number of objects and report to the instructor.

(*e*) Imagine the millimeter scale to be magnified ten times and draw in your notebook a scale ten times as large as the one you have been studying, that is, let 1 cm. represent 1 mm. Draw a vernier scale adjacent to the scale which you have just drawn letting each vernier division be represented by $\frac{9}{10}$ cm. and having ten such divisions. Fig. 3 shows such a scale with the zero lines coinciding.

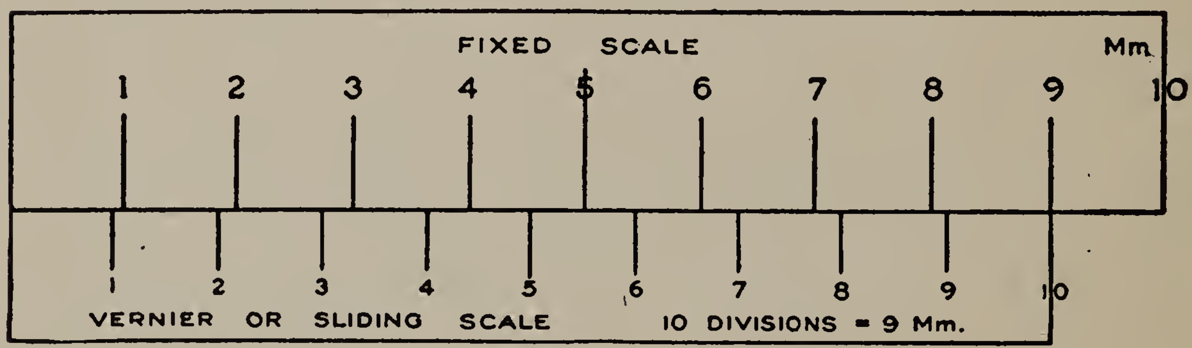


FIG. 3.

In your drawing, represent the vernier moved over until the zero lines are $\frac{3}{10}$ cm. apart.

(*f*) (Optional.) Measure with the vernier caliper a number of twist drills and check your results by means of the values marked on the drills; or measure a number of wires and check your results by means of a wire gauge. Get the number of the wire by means of the gauge; and by reference to Table 6 in the appendix find the diameter.

Materials Required.—Vernier caliper with millimeter scale; vernier caliper with inch scale; twist drills; wires and B. & S. wire gauge.

EXPERIMENT 5

THE MICROMETER CALIPER

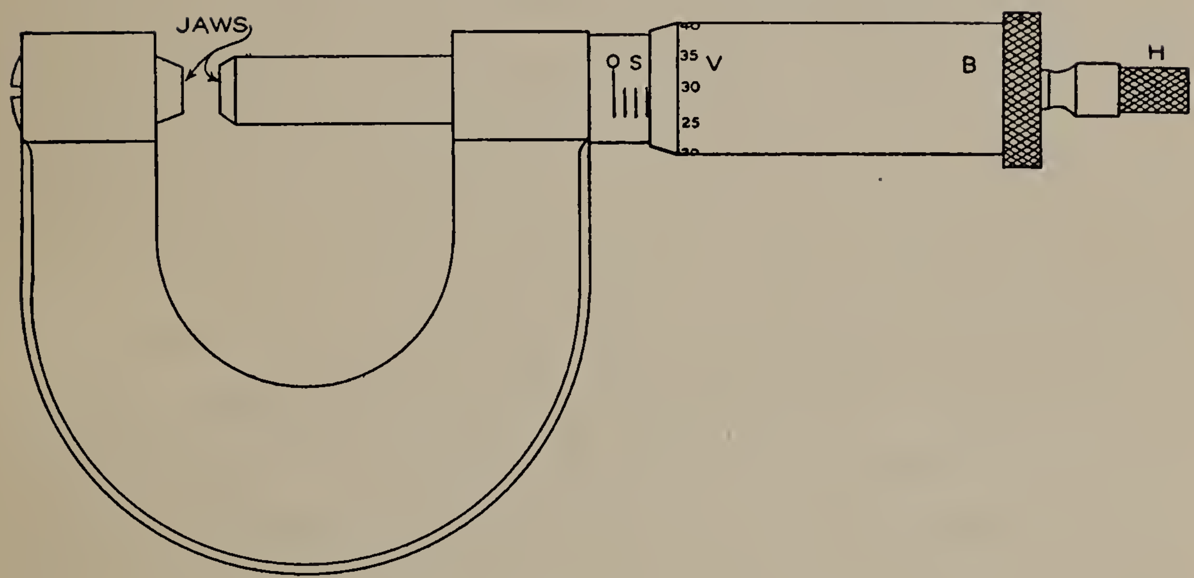


Fig. 4.

Introductory Discussion.—The micrometer caliper is used for very accurate measurements. It can be employed for work for which the vernier caliper is not sufficiently accurate. With a micrometer caliper the diameter of a wire can be measured in thousandths of an inch or hundredths of a millimeter.

In using the micrometer caliper very light pressure must be used in closing the jaws. This is usually provided for by a ratchet head (*H* in Fig. 4). The jaws are closed by turning the ratchet head. When the jaws are in contact, the barrel, *B*, stops turning and the ratchet continues to turn. Stop turning when two or three clicks are heard. If there is no ratchet on the instrument you are using, close the jaws by turning the barrel, *B*, using very light pressure.

I. Metric Measurements

(*a*) Close the jaws of the caliper. The zero line of the scale, *V*, should now fall exactly on the line which runs lengthwise on the stem, *S*, and the edge of the barrel should rest exactly on the zero line of the scale, *S*. Now turn the barrel back, counting the number of revolutions until the edge lies exactly on the 1-mm. mark. You have opened the jaws 1 mm. How many revolutions were required? One revolution, then, opens the jaws how far? One division on the barrel is what part of a revolution? If the barrel is turned just one division, the jaws are opened what fraction of a millimeter?

(*b*) Set the caliper to read 1.25; and show it thus set to the instructor. Set it to read 1.65 mm.; 2.75 mm. Measure the diameter of a wire and report your result showing the instrument to the instructor as you have set it for the reading. When you have learned how to use the instrument, measure a number of wires. Check by getting the number of the wire with a wire gauge and finding in Table 6 in the appendix the diameter of the wire. Record the results in your notebook.

II. English Measurements

(*c*) If the caliper you are using is marked in fractions of an inch, find first the length of one division on the fixed scale, that is the scale running lengthwise on the stem. Find next the value of one revolution of the barrel, that is, how far the jaws are opened when the barrel is turned one revolution. Next note how many divisions there are on the circular scale and the value of one of these divisions. In other words answer the question, "What fraction of an inch are the jaws opened if the barrel is turned only one division of the circular scale?"

Measure a wire showing the instrument as you have set it to the instructor and stating your result. Repeat with different wires and check your results by reference to Table 6 as directed in paragraph (*b*).

Materials Required.—Micrometer caliper; wire gauge; wires to be measured.

EXPERIMENT 6

WEIGHT OF WATER (Cylinder Method)

What is the weight of a cubic foot of water? Of a liter of water?

What to do:

(*a*) Secure a cylindrical calorimeter. By means of your metric-English ruler measure very carefully the inside diameter and height, both in centimeters and in inches. Estimate your values to millimeters in the metric system and to tenths of an inch in the English system. Divide the height of the cylinder as you have found it in the metric system by the height as measured in the English system. What does this ratio indicate?

(*b*) Now from your figures using the formula given below calculate the volume of the calorimeter in cubic inches and also in cubic centimeters.

$$\text{Volume} = \text{area of base} \times \text{height} = \frac{\pi D^2 H}{4}$$

In which D is the diameter of the cylinder and H is the height.

(*c*) Now place the calorimeter on a trip scale and find its weight, first in pounds and then in grams. Record these two values.

(*d*) Now fill the calorimeter with water and weigh again in both units. Subtract the weights of the calorimeter as found above from the weights just found and the results will be the weight of the water placed in the calorimeter.

(*e*) Divide the weight of the water by the volume of the

cylinder. This will give the weight of a cubic inch of water and using the metric units the weight of a cubic centimeter of water.

(*f*) From these values calculate the weight of a cubic foot of water and also a liter of water (a liter = 1,000 c.c.).

Record all your results in the following form:

	English	Metric
Length		
Diameter		
Volume		
Weight of calorimeter		
Weight of filled calorimeter		
Weight of water		
Weight of water ÷ volume		
Weight of cubic foot of water		
Weight of liter of water		

Materials Required.—Cylindrical calorimeter; metric-English ruler; trip scale; metric and English weights.

EXPERIMENT 7

WEIGHT OF WATER (Burette Method)

Introductory.—The burette is essentially a glass tube of uniform bore carefully graduated to show volumes (c.c.). In some, the lower part tapers to a tube to fit ¼-in. rubber tubing, which with a pinch-cock controls the flow of liquid; in others, control is had by a glass spigot. For convenience in use, the graduation of the stem is generally from the top down.

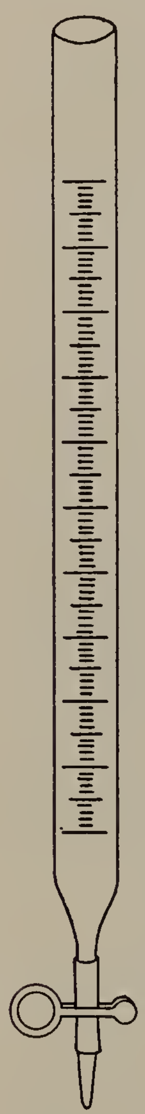


Fig. 5.

What to do:

(*a*) Fix the burette in an upright position by means of a rod support and a clamp. Fill with clean water beyond the zero line. Notice that the top level of the water is not horizontal, the edges clinging to the walls of the tube. Readings must, therefore, be taken across the horizontal portion of the water column.

(*b*) Restricting the outflow to drops, withdraw enough water to bring the top level to the zero line. Empty your catch basin, and get its weight to tenths of a gram. Replace it under the burette. Record its weight.

(*c*) Now release any known volume of water, say 5 c.c. Find the net weight of the given volume. What is the weight of 1 c.c.?

(*d*) Release in succession any known volume of water, say 25 and 50 c.c. respectively, and get their net weight, separately. Do these net weights confirm your conclusion (in *c*) as to the weight of 1 c.c. of water?

Materials Required.—Burette; trip scales; set of weights; *clean* water; ring stand with clamp.

EXPERIMENT 8

HOUSEHOLD MEASUREMENTS AND WEIGHTS

What to do:

Make measurements as called for in the following tables, first leveling off with the sharp edge of a knife. Tabulate as follows:

I. TABLE OF VOLUMES

...... teaspoonfuls (t)	= 1 T (tablespoonful)
...... T	= 1 c (cupful)
...... c	= 1 pt. (pint)
...... pt.	= 1 qt. (quart)
...... qt.	= 1 gal. (gallon)
...... gal.	= 1 pail

II. TABLE OF WEIGHTS

Number of cups	Material	Weight
....	Flour	1 lb.
....	Granulated sugar	1 lb.
....	Powdered sugar	1 lb.
....	Coffee	1 lb.
....	Water	1 lb.
....	Milk	1 lb.

III. WEIGHTS OF COMMON HOUSEHOLD VOLUMES (WATER)

Kitchen cup	=	oz.
Teacup	=	oz.
Pint	=	oz.
Quart	=	lb.
Gallon	=	lb.

Materials Required.—Scales; measures and items as shown.

2

EXPERIMENT 9

ARCHIMEDES' PRINCIPLE

How much weight does an object appear to lose when it is submerged in water?

What to do:

(*a*) By means of a spring balance and a cord find the weight of a small stone. A piece of granite or other stone

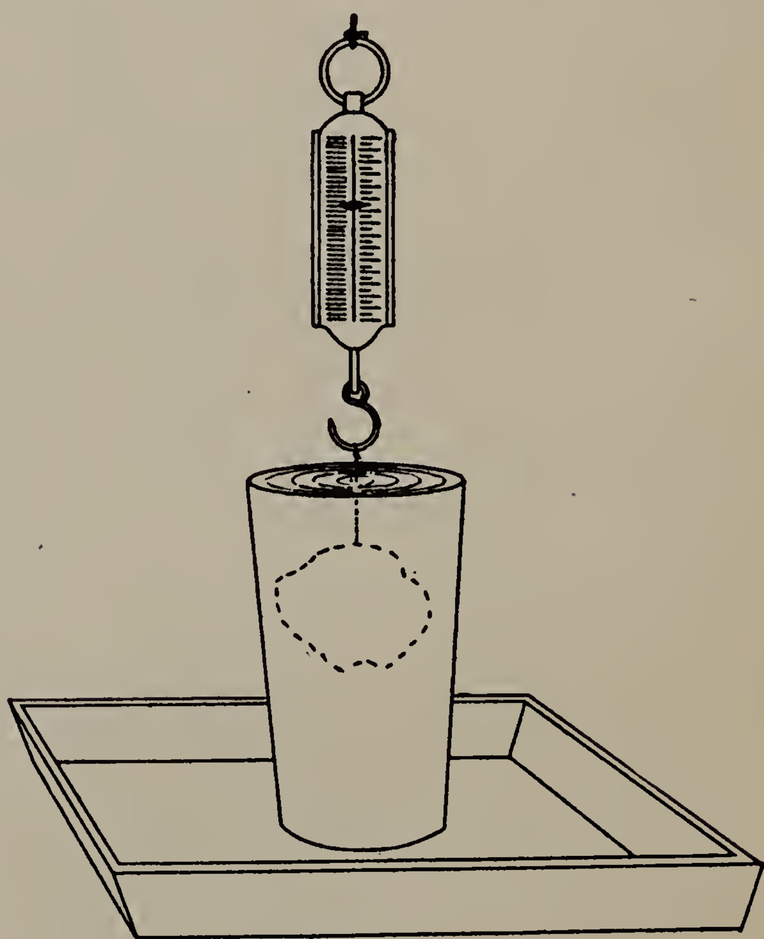


Fig. 6.

weighing between 1 and 2 lb. is good for this experiment. Having the stone suspended from the spring balance lower it into a jar of water. Note the weight when the

stone is entirely submerged but not touching the sides or the bottom of the jar. How much weight does the stone appear to lose?

(*b*) Fill a metal cup quite full of water and place the cup in a glass tray to catch the water which overflows (see Fig. 6). A lemonade shaker may be used as a cup for this experiment. Tie a thread around the stone and slowly lower it into the cup until it is completely immersed.

(*c*) Remove the cup and its contents carefully from the tray. Find the weight of the water in the tray by weighing it in a cup or beaker on the trip scales. This is the weight of the water that was crowded out or displaced by the stone. How does this weight compare with the weight lost by the stone?

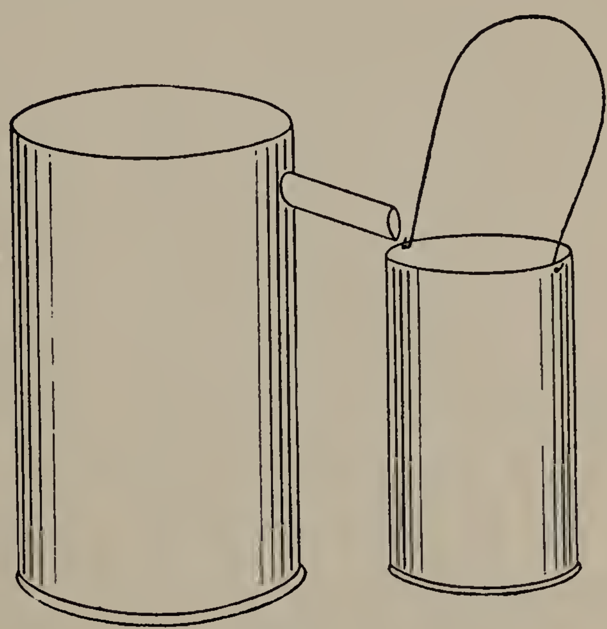


FIG. 7.

An overflow cup (Fig. 7) may be used instead of the lemonade shaker. Fill the overflow cup until the water begins to run out of the spout. Then place a cup which has been weighed, under the spout. Slowly immerse the stone in the overflow cup. The water which overflows is caught in the second cup and weighed.

State Archimedes' principle and tell how this experiment illustrates the principle.

Materials Required.—A lemonade shaker or an overflow cup, a second cup or beaker for catching the water that overflows, a glass tray, spring balance, trip scales, stone, thread.

EXPERIMENT 10

LAW OF FLOATING BODIES

What weight of water does a floating body displace?

What to do:

(*a*) Find the weight of a piece of wood which is 1 cm. square and 30 cm. in length, weighted at one end. Float it in water with the weighted end down, using a hydrometer jar (Fig. 8). What is the length of the part that is below the surface of the water? What is the volume of the submerged portion of the stick? How many cubic centimeters of water are displaced by it when it is floating? Knowing that 1 c.c. of water weighs 1 gram, what is the weight of water displaced by the piece of wood? How does the weight of the displaced water compare with the weight of the stick? Is the weight of the displaced water equal to the weight of the part that is submerged or to the weight of the entire piece of wood?

(*b*) If the stick were floating in a liquid more dense than water would it sink deeper or not so deep as in water? Try this by floating it in a strong salt solution. What volume of the salt solution does the stick displace? What weight of the salt solution does it displace? To find the answer to the last question weigh a specific gravity bottle which holds 25 c.c. Then fill the specific gravity bottle with the salt solution and weigh it. Having the weight of 25 c.c. of the salt solution, find the weight of the solution displaced by the stick. Does the principle illustrated for water in paragraph (*a*) hold good for a liquid denser than water?

(*c*) (Optional.) Make a test like that in paragraph (*a*) using a piece of wood 1 in. square and 12 in. in length. The weight of a cubic foot of water is 62.5 lb. Compute the weight of the water displaced by the stick and compare with the weight of the rod.

Answer the question asked at the beginning of the experiment.

Questions.—1. What is meant by the displacement of a ship?

2. Why is the water line of a freighting steamer above the water when the steamer is unloaded?

3. If this line is at the surface of the water when the steamer is on a fresh water lake and the steamer sails out on the ocean will the line be above or below the surface of the water?

Materials Required.—Wooden stick 30 by 1 by 1 cm. weighted at one end; wooden stick 12 by 1 by 1 in. weighted; hydrometer jar; salt solution; specific gravity bottle 25 c.c.; trip scales.

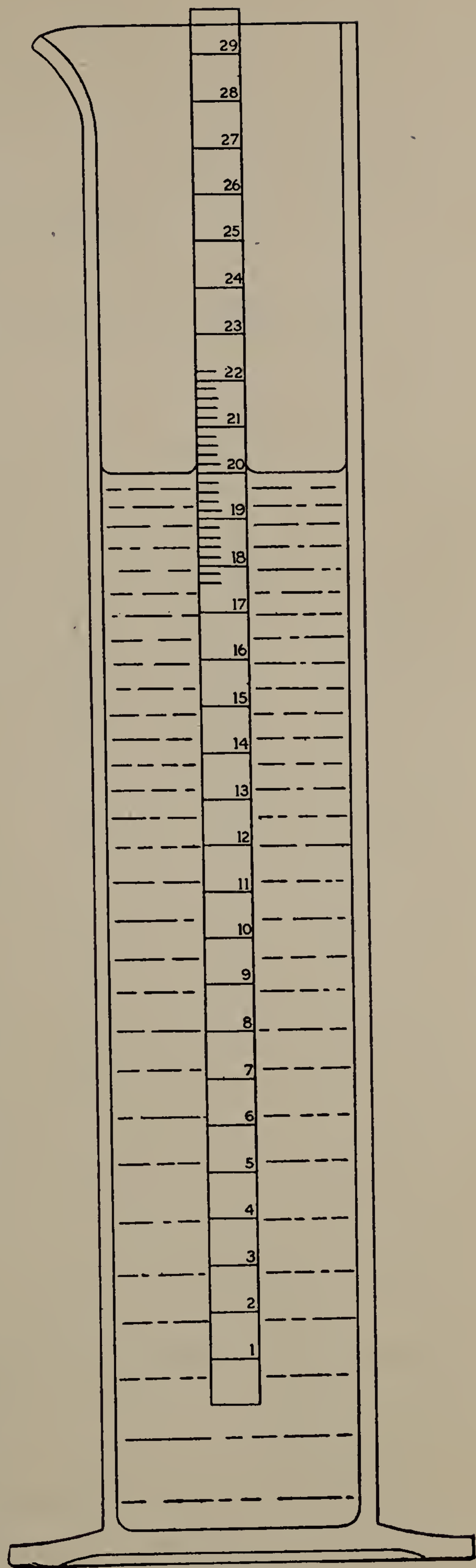


FIG. 8.

EXPERIMENT 11

DENSITY BY WEIGHT AND MEASUREMENT

What to do:

(*a*) Measure the length, width, and thickness of a wood block in centimeters and find its volume in cubic centimeters. What would an equal volume of water weigh? Weigh the block. Divide the weight of the block by the weight of an equal volume of water. This ratio is the specific gravity of the wood. It is also the density since it is the weight in grams of a cubic centimeter of the wood. The density of any material is the weight of unit volume of that material. In the metric system density is the weight of 1 c.c. In the English system density is the weight of 1 cu. in. or of 1 cu. ft.

(*b*) Find the volume of the block in cubic inches. Having given the weight of a cubic foot of water (62.5 lb.), compute the weight in ounces of a volume of water equal to the volume of the block. Find the weight of the block in ounces and divide the weight of the block by the weight of an equal volume of water. How does this ratio compare with the one found in (*a*)? The specific gravity of any material is its weight divided by the weight of an equal volume of water. Specific gravity may be found by the use of either metric or English units. Which is the simpler?

It would be well to test different kinds of wood, at least one kind that is more dense than water and one that is less dense than water. See Table 9 in appendix.

(*c*) Test in the same way pieces of iron, aluminum, and copper of regular form, using metric units.

Materials Required.—Rectangular wooden block; rectangular pieces of iron, aluminum and copper of regular form [rectangular or cylindrical]; balance and weights.

EXPERIMENT 12

TESTING THE DENSITY OF MILK (Household Method)

What to do:

(*a*) Weigh a cup carefully to tenths of a gram.

(*b*) Using the same cup and leveling off with the sharp edge of a knife to make sure of the volume, weigh the cup full of water.

(*c*) In the same way weigh the cup full of milk.

(*d*) Compute the density of milk, using water as unity.

(*e*) How would more water affect the density of milk? More butter fat? More cream? Dirt? Would the weight of the milk change after standing 15 hours for the cream to "rise"? Would the density be affected by such standing?

Materials Required.—Cup of milk; cup (or beaker); trip scales; knife.

EXPERIMENT 13

SPECIFIC GRAVITY BY MEANS OF ARCHIMEDES' PRINCIPLE

Introductory Discussion.—The specific gravity of any object is the ratio of the weight of that object to the weight of an equal volume of water. If the object is irregular in shape it is difficult to find its volume by measurement but by applying Archimedes' principle we can easily find the weight of an equal volume of water.

What to do:

(*a*) Weigh a small stone or other object to be tested by the usual method using trip scales or beam balance.

(*b*) Suspend the object by a thread from the balance. Place a glass tumbler or a battery jar containing water under the balance in such a way that the object is completely submerged in the water but does not touch the side or the bottom of the jar. Find the weight of the object when submerged.

In most laboratory balances a special device is provided for this test. In the trip scales a place for attaching the thread can be found directly under the center of the platform of the scales. The scales must be supported at an elevation of a foot or more above the table. If a beam balance is used for this experiment it must have a counterpoise to replace one of the pans. The object is suspended from this counterpoise.

(*c*) What is the loss of weight of the object when submerged in water? To what is this loss of weight equal

according to Archimedes' principle? Find the specific gravity of the object. Find the specific gravity of a number of different materials and record the results in the following form:

Materials	Weight in air	Weight in water	Loss of weight	Volume	Density as determined	Standard values	Difference
Granite............							
Coal...............							
Iron (cast)..........							
Glass...............							
Brass...............							
Copper.............							
Aluminum..........							
Carbon.............							
....							
....							

Materials Required.—Balances; cord for support; battery jar; water; various articles for testing.

EXPERIMENT 14

THE SPECIFIC GRAVITY BOTTLE

What is the easiest way of finding the density of liquids?

A specific gravity bottle is simply a carefully made bottle with stopper and neck nicely fitted, the stopper having a longitudinal bore of about 1 mm. to allow the escape of any surplus liquid as the stopper is inserted, and to assure thereby a constant capacity for the bottle at a given temperature. Handle carefully, as the walls are thin, and glassware thus made is expensive.

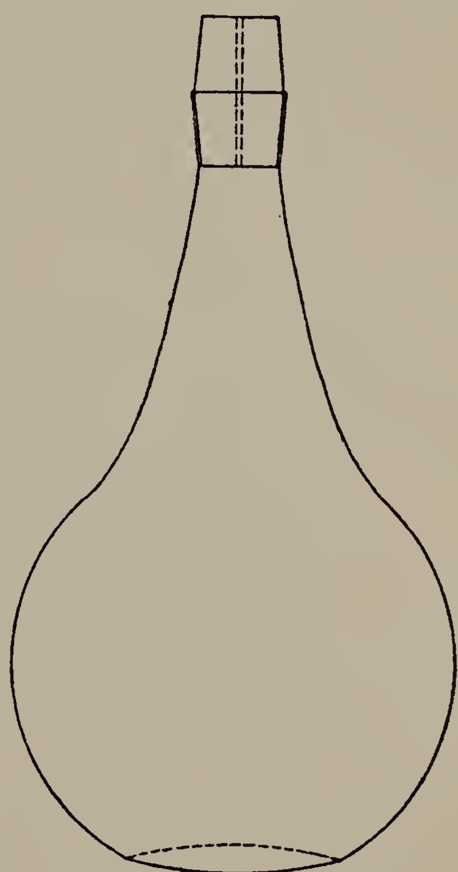


Fig. 9.

What to do:

(*a*) See that the bottle is dry. Then weigh carefully.

(*b*) Fill to the neck with clean water, wiping off any surplus that may cling to the stopper or walls.

(*c*) Weigh the bottle and contents. Subtract the weight of bottle, as determined in (*a*). The remainder represents the net weight of contents of bottle. Therefore the capacity of the bottle is what? How does this capacity compare with the rated capacity as shown on the walls of the bottle? Use your determination of its capacity as the real capacity of the bottle at the temperature of the liquid. Empty the bottle.

(*d*) Fill successively with other solutions, recording results in the following form:

Bottle No.......................
Net weight......................
Rated capacity..................
Tested capacity.................

	Gross weight	Net weight	Volume	Density as determined
Water................				
Alcohol...............				
Copper sulphate........				
Salt brine.............				

Materials Required.—Specific gravity bottle; balances weighing to decigrams; weights; various solutions as shown in table.

EXPERIMENT 15

DENSITY OF FLOATING BODIES

How shall we find the density of irregular materials that float in water?

Discussion.—The difficulty of this problem lies in the fact that a piece of wood thrown into water floats, and therefore the displacement seems hard to determine. In the first place, we learn from Archimedes' principle that a floating body sinks till it displaces its own weight. Hence if we get the weight in air (say 400 grams), we know the weight of the water displaced, and therefore by deduction the volume of the displacement. If now we attach a sinker of known weight in water to the block, and find it loses say 100 grams, we know the 100 grams represent the force required to displace the 100 c.c. not submerged before the sinker was attached. The volume of the wood must therefore be the sum of the original displacement (400 c.c.) and the 100 due to the weight of the sinker equal to 500 c.c. Now if the volume is 500 c.c. and the weight is 400 grams, we know at once the weights of equal volumes of water and wood to be 500 and 400 grams respectively, and the density must equal

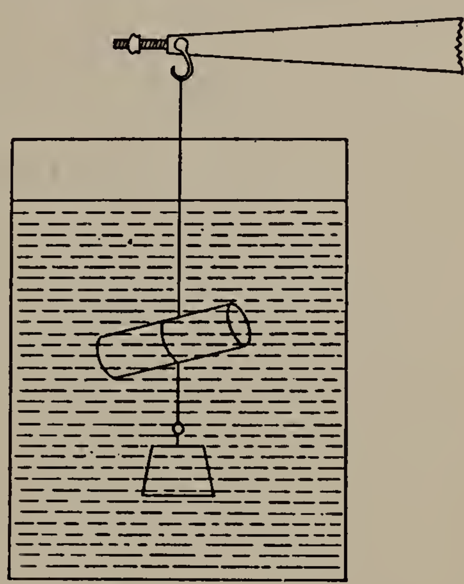


FIG. 10.

$$\left(\frac{400}{500}\right) = 0.8$$

What to do:

Weigh the wood in air. Weigh the sinker in water. Attach the wood to the sinker, and find the weight of the combination in water. The weight of the wood in air plus the loss of weight of sinker in water gives the volume of the displacement in cubic centimeters, and this readily gives by deduction the weight of an equal volume of water. We now have the weights of equal volumes of wood and water, and this ratio is the density required.

Record results in following form:

Materials	(1) Weight in air	(2) Weight of sinker in water	(3) Weight of both in water	(4) Apparent loss of weight of combination	(5) Weight of water displaced	Volume = numerical sum of (1) and (4)	Density as determined	Density from table
Wood........								
Cork.........								
Paraffine.....								

Materials Required.—Balances; weights; battery jar; materials for testing, wood, cork, paraffine; cord for attaching sinker; sinker.

EXPERIMENT 16

DENSITY FROM EQUAL WEIGHTS OF LIQUID COLUMNS

Introductory.—If a common lift pump be used to lift liquids of various densities, it will be found that the height to which liquids may be raised by "suction" have a direct relation to the densities of the liquids used. For

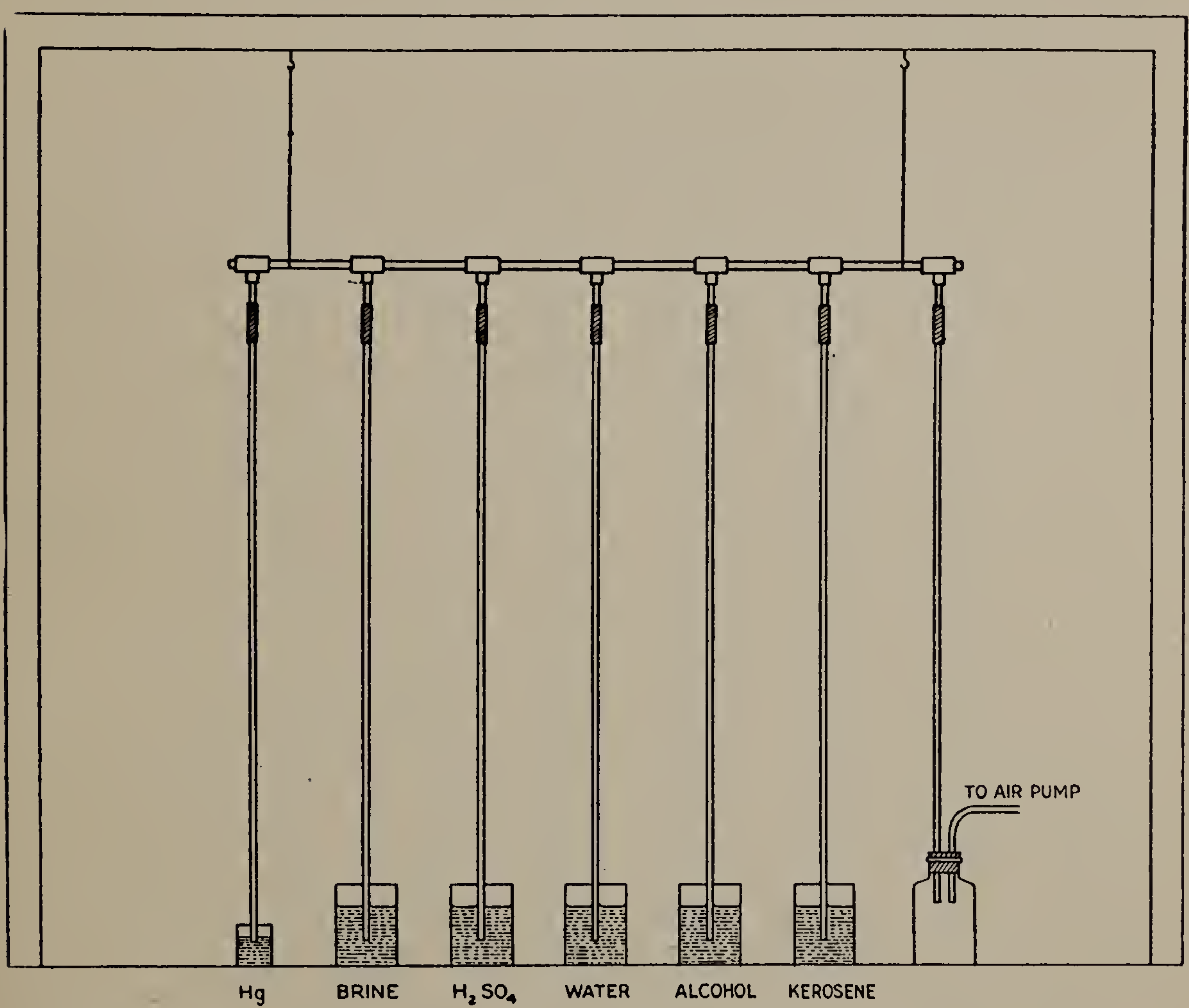


FIG. 11.

example, when water can be lifted 34 ft., alcohol can be raised 42.5 ft., mercury 30 in., etc. Similarly, if apparatus be used connecting through separate outlets with a group

of liquids and the air pressure be lessened by "suction," the liquids under action of the same force rise to different heights. All the liquid columns, measured vertically, have the same pressure and consequently the same weight, provided the tubes have the same diameter. Their densities can then be computed by comparison of the different heights referred to water as a standard.

What to do:

(*a*) See that the tube connections are air-tight and the pinch-cock rightly placed (see Fig. 11). The tubes must extend far enough into the liquids so that their lower ends will not be uncovered as the liquids rise in the columns.

(*b*) Through a mouthpiece suck enough air out of the tubing (a single stroke from the air pump is a far better way of doing it) to make the alcohol rise almost to the top. Close the tube by the pinch-cock excluding the outside air. This unbalances the pressure inside and outside the tubing. To restore the balance, the liquids rise to different heights.

(*c*) Measure vertically the height to which the water has risen in its tube.

(*d*) Repeat (*c*) for each of the other liquids. It is essential that during these measurements the fittings be air-tight as well as the pinch-cock.

(*e*) Suppose the water comes to rest at a height of 60 cm. above the level of the water in the jar below, and the alcohol at 75 cm. Then the density of the alcohol is represented by the ratio of 60 divided by 75, or 0.8, since the columns have equal diameters, are subjected to the same air pressure, and have therefore the same weight.

(*f*) Consult the mercury barometer and find out how high the mercury would stand in its tube if you could completely exhaust the air from the top of the tubing.

(*g*) Record results as follows:

	Height under partial vacuum (observed height)	Height under complete vacuum	Density as calculated	Density from table
Water..................				
Salt brine..............				
Kerosene...............				
Alcohol................				
Sulphuric acid..........				
Mercury...............				

Materials Required.—Six cups or bottles; glass or brass tubing with six outlets on one side; or, ⅛-in. gas pipe lengths of about 10 cm. each, fastened together by "T's" and the two opposite ends of the pipe thus made closed by plugs; short pieces rubber tubing for connections; six pieces glass tubing (¼ in.) 75 cm. in length; 2 to 6 oz. each of water, salt brine, kerosene, alcohol, sulphuric acid, mercury; pinch-cock.

EXPERIMENT 17

DENSITY AS A MEASURE OF COMMERCIAL VALUE

Introductory.—Really serviceable hydrometers are now so common and inexpensive that tests of various liquids in common use are of great interest, and serve to fix in mind the practical uses of density as a means of determining value. For class use, it is best to have one hydrometer for each of the groups to be tested, so as to avoid mixing the materials even though careful rinsing is done. Suggested groups are milk, alcohol, oils, alkalies, and acids.

To avoid the danger of spilling, it is best to have a rack of sufficient size to hold rigidly the samples of each group in proximity. Remember the danger of burning the fingers from contact with strong acids or alkalies. Rinse well immediately if any gets on the hands.

Record results as follows:

Material	Kind	Density
Milk...Test 1		
Test 2		
Test 3		
Alcohol		
Alcohol		
Alcohol		
Oils	Kerosene	
	Gasoline	
	Benzine	
	Lubricating	
Alkalies	Caustic soda	
	Caustic potash	
	Lime	
	Sal ammoniac	
Acids	Sulphuric	
	Hydrochloric	
	Acetic	

Part II (Optional)

An important commercial use of density is found in the storage-battery cell. When fully charged, the cell shows a density of about 1.200, the solution being generally dilute sulphuric acid. When fully discharged, the density falls to about 1.130. Since there is a definite fall in density for a certain discharge of the cell, it follows that the density furnishes a sure test for the state of charge of the cell. For example, if the density when fully charged is 1.200, and when tested after discharging a while shows 1.165, it follows that the cell is half discharged.

It is recommended in this experiment that tests for density of a storage battery solution be made through all the stages of charge and discharge—work requiring from 5 to 8 hours at least. For further explanation and detail, see experiment No. 104.

Materials Required.—Hydrometers; water for rinsing; various grades of oil, alcohol and milk; different acids; solutions of caustic soda; copper sulphate, sal ammoniac, etc.

EXPERIMENT 18

WEIGHT OF AIR

Introductory.—We have found the density of stone, of lead, of iron, and of other things. This determination was possible because these materials could be weighed and their volumes computed, from which facts the relative weights of equal volumes of water and the tested materials give the densities. But can the density of air containing water vapor and other gases be found? It can, if accurate weighings can be had.

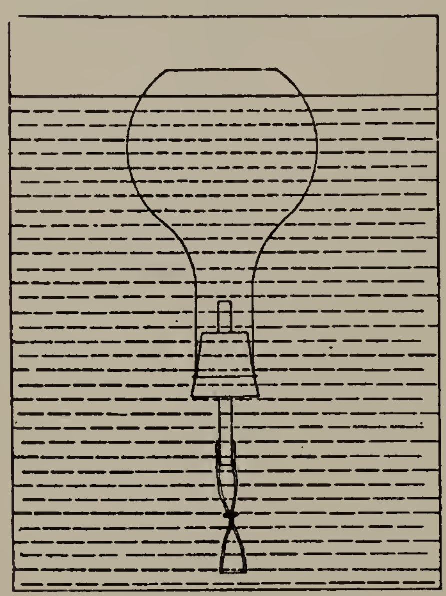


FIG. 12.

What to do:

Provide Florence flask of about 500 c.c. capacity, fitted with a one-hole rubber stopper (cork is too porous), through which runs a short glass tube of about ¼-in. bore. Over glass tubing slip rubber tubing provided with a pinch-cock having a strong spring.

Now weigh the flask and attachments. Removing the pinch-cock, attach rubber tube to air pump, and exhaust for not less than 5 minutes. Attach pinch-cock to rubber tubing again, making sure that the walls of the tubing are tightly held. Detach flask from the air pump and weigh carefully again. Put tube below surface of water in the jar. Open pinch-cock slowly letting the flask fill. Finally,

push the flask itself, mouth downward, into the water so that the water levels in the flask and the jar are the same. Now close tube by means of pinch-cock, remove flask from water, open pinch-cock, and pour water out into a graduate. Note the amount, from which can be readily had the volume of the water in cubic centimeters. This volume represents the number of cubic centimeters of air exhausted, the weight of which can be computed from data first obtained. But density, whether of liquids, solids or gases, is weight divided by volume. We now have both weight and volume for air.

Record results as follows:

Weight of flask and attachments (air-filled)	....
Weight of flask and attachments (exhausted)	....
Difference between these weights	....
Measured volume of water	....
Number of cubic centimeters of air exhausted	....
Density of air (referred to water as a standard)	....
Density of air (referred to air as a standard, Table 12)	....

Materials Required.—Air pump; Florence flask (500 to 1,000 c.c.); 4-in. rubber tubing; 4-in. glass tubing; battery jar containing water; balances accurate to centigrams; pinch-cock.

EXPERIMENT 19

LIFT PUMP

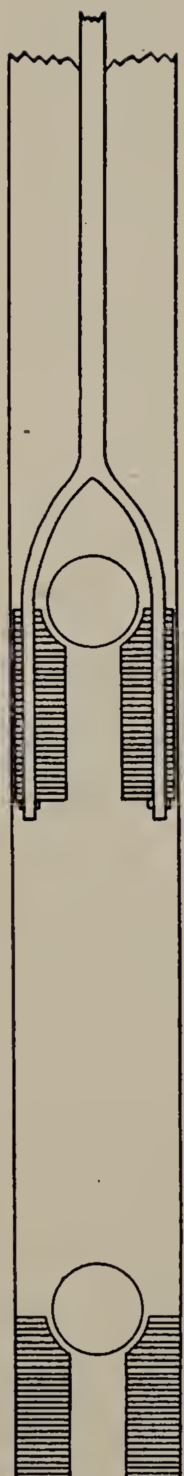


FIG. 13.

It is highly desirable in this experiment that the pump stock (chamber) be of glass in order that the experimenter may watch the action of the valves as well as the movement of the water. Before trying to pump water, see that the valves move freely without "catching" on the valve-seats.

What to do:

(*a*) Insert lower end of pump into the jar below the water level. Does the water enter the pump stock? Now pull the piston up the full stroke. Does either valve open? Does the water level rise in the pump? If, while you hold the piston at a fixed height, the water should fall in the pump, it indicates a leakage in the valves.

(*b*) Now push the piston down, still holding the lower end of the pump below the water level. Which valve opens? Does any water leave the pump while the piston is lowered? Repeat the strokes several times, noting any effect on the height of the water in the pump. What is the main good done by the first few strokes?

Record results of your observations as follows:

	Strokes					
	1 up	1 down	2 up	2 down	3 up	3 down
Position upper valve......						
Position lower valve......						
Action of water..........						

Supposing that you could pump out all the air above the water in the pump stock, how high would the water stand? Consult your barometer; and remembering that mercury is 13.6 times heavier than water, compute the extreme distance the piston may be above the water and still operate at the observed air pressure.

Materials Required—Laboratory pump; battery jar; water.

EXPERIMENT 20

THE SIPHON

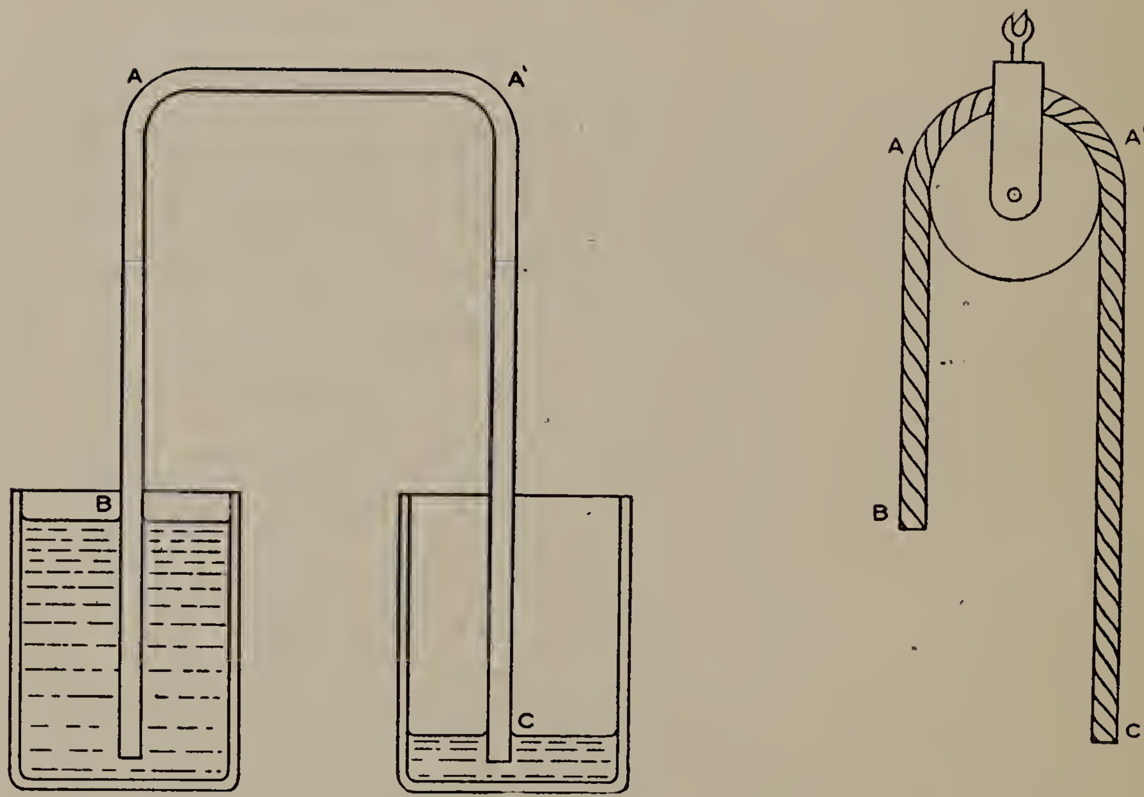


FIG. 14.

How can a tank of water be emptied without tapping the bottom or the sides; that is, how can the water be made to flow out over the top of the tank? What causes the water to flow?

What to do:

(*a*) Fill two jars half full of water and place them adjacent, one on a block to raise it several inches higher than the other. Immerse a rubber tube in the water of one jar so as to fill the tube with water. Then grasping one end of the tube air-tight with one hand, with the other hand throw the other end of the tube into the other jar and let go of the tube ends.

Do you notice any flow of water from one jar to the other? Try the effect of changing the water levels of the jars by holding one higher than the other alternately. Reverse several times and notice the effect. Is there any current flowing when the water levels are the same? In what way can you increase the rate of flow? In what way (without removing the tubes from the water) can you check the flow altogether?

(*b*) To learn the cause of the flow arrange the siphon as in Fig. 14, the tube being filled with water, one jar being nearly full, the other containing only a little water. Consider first the pressure of the air on the water in the two jars. The air pressure at *B* tries to force the water up the tube from *B* toward *A* and over to *C*. On the other hand, the air pressure at *C* tries to force the water up the tube from *C* and over toward *B*. These two pressures then oppose each other. They are practically equal, hence cannot cause the water to flow in either direction. The only use of the air pressure is to keep the tube filled with water. Consider next the pressure of the water in the tube. Which is greater, the pressure of the water from *A* to *B* or the pressure of the water from *A′* to *C*? The water flows in the direction of the greater pressure. To understand this more clearly compare the siphon with the rope and pulley on the right-hand side of Fig. 14. The end of the rope *A′C* is heavier than the end *AB* just as the column of water *A′C* has greater pressure than *AB*. The rope runs off the pulley in the direction of the greater weight just as the water flows through the tube in the direction of the greater pressure. The rope is held together by its own cohesion. The water is held together by air pressure.

(*c*) The two arms of the siphon, *A′C* and *AB*, are known as the long and the short arm respectively. There is no

limit to the length of the long arm but the length of the short arm is limited by the height to which air pressure can hold up a column of water. The mercury barometer shows the height to which air pressure can hold up a column of mercury. A water column 13.6 times as high as the mercury column could be sustained by the air pressure. Why? Read the barometer and find the maximum length of the short arm of the siphon. Make a drawing to scale showing a siphon extended to the maximum height of the short arm, letting 1 cm. represent 2 ft.

Questions.—How could a barrel be emptied by a person too weak to tip it over?

Can you think of any useful applications of the siphon?

Materials Required.—Two glass jars; rubber tube.

EXPERIMENT 21

FAUCETS

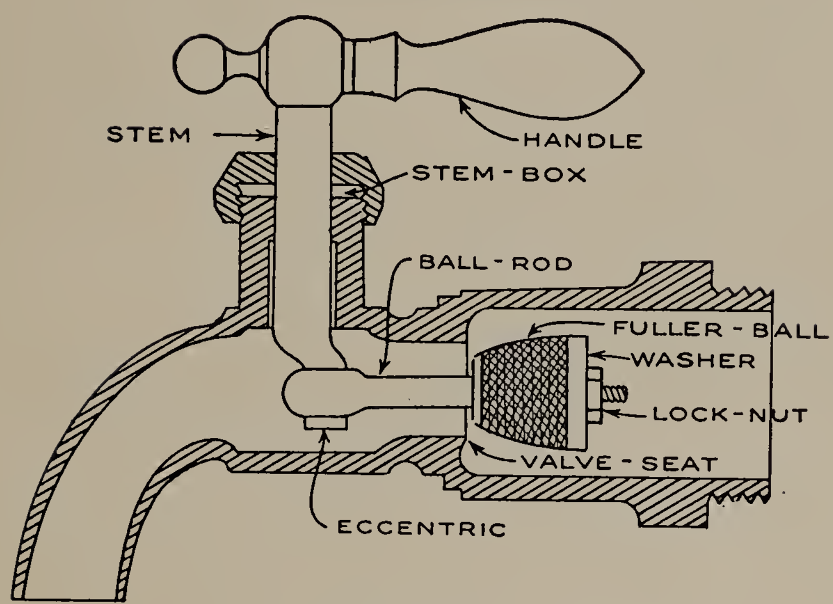


FIG. 15.

What is the main function of the ordinary water faucet? Where is it used and why?

What to do:

(*a*) Secure from the instructor a water faucet which has been cut open so that the working parts are exposed. Make a careful drawing of the apparatus as shown. On your sketch indicate the following parts: handle, stem, stem-box, eccentric, ball-rod, Fuller-ball, washer, lock-nut, and valve-seat. State the use of each part in the operation of the faucet.

(*b*) If a compression faucet is at hand make the same analysis of it.

Questions.—1. In opening the faucet, must any pressure be overcome?

2. What keeps the Fuller-ball in place?

3. In what places should faucets be used and in what places should valves be used?

4. Which of the two types of faucets is the better and why?

5. In case of failure of operation the trouble may lie with the Fuller-ball or with the eccentric. If the ball shows evidence of disintegration can you find a simple way to replace it? How?

Materials Required.—Faucets of the Fuller-ball and Compression types which have been sectioned so that the working parts have been exposed.

EXPERIMENT 22

THE "VACUUM" CLEANER

Introductory.—The use of an air appliance for cleaning rugs and upholstery is now so common that the principle involved deserves laboratory illustration. One of the three types is here selected because so easily made from the mounted blades of the ordinary ventilating fan put over the armature shaft of a small motor (say ⅛ hp.). It is essential that the collar to which the blades are

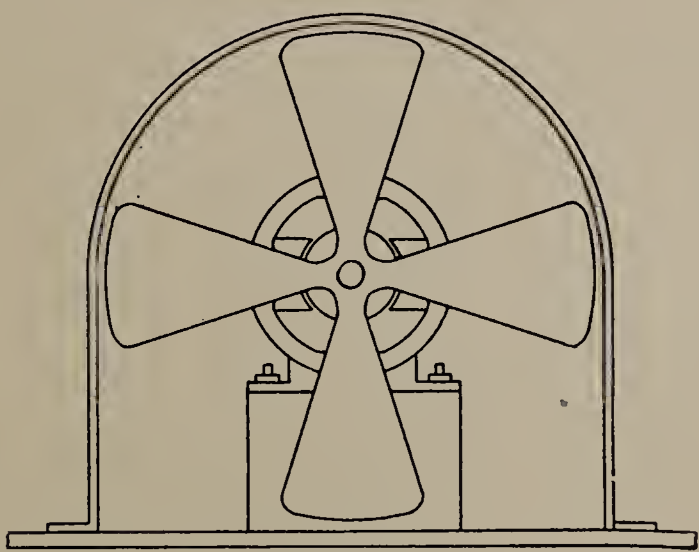


FIG. 16.

attached be tight-fitting and securely attached to armature shaft, of course being exactly balanced to avoid vibration. A hood made of sheet iron, open at both ends, and fitting loosely over the motor and blades serves the double purpose of giving definite direction to the air currents set in motion, and of providing a necessary safety device (these blades rotating at high speed, if not protected, are dangerous). Further protective as well as useful

features are wire meshes put across the two open ends, either loosely or attached rigidly to the iron hood. This form of cleaner has the double advantage of having all the parts readily accessible for inspection and of being easily made from a motor usable for many other purposes.

What to do:

(*a*) Make a draft indicator consisting of a ribbon a few inches long tied to one end of a stick of wood.

(*b*) Start the motor. Holding the ribbon in the air current on the outflow side, determine: (1) the direction of the air current with reference to the axis of the fan; and (2) the center of greatest intensity of air outflow. When you have found this center of greatest outflow, mark it on the wire meshing, and attach your ribbon there.

EXPERIMENT 23

TRAPS AND SOIL PIPES

Why is a trap inserted in a drain pipe?

Why is it so called?

What to do:

(*a*) Build up a trap as is indicated in the sketch. Support it by means of a ring stand and be sure you have a jar under the drain pipe (*D*), in the sketch, in which to collect the water inserted in the funnel. Pour a small quantity of water (a tumblerful) into the funnel and watch its progress down the pipe. Does all of the water go through? Why not?

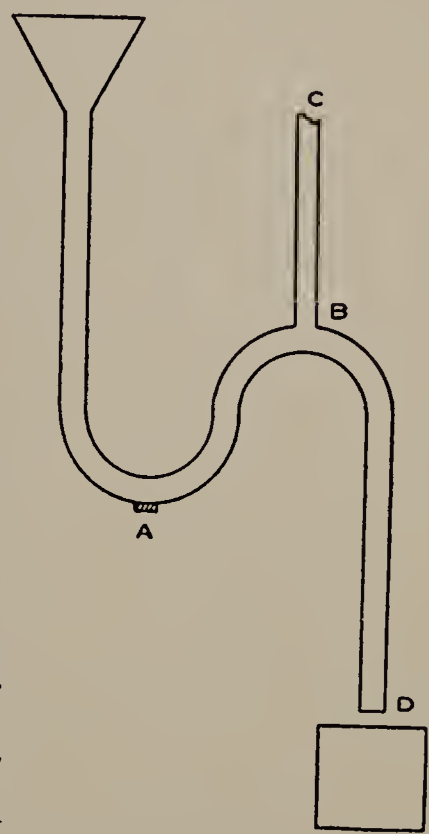


FIG. 17.

(*b*) Now pour another tumblerful into the funnel *slowly*. Did all of this water pass through? Explain. Is the trap (*A*) of the sketch completely filled with water? Why not?

(*c*) Now place your finger over the open end of pipe (*C*). Pour a glass of water into the funnel and note the effect. This pipe is called "the vent."

(*d*) Examine the drain pipe of the sink in your home. You will find that it is provided with a removable plug at point "*A*". What is its function? What is the reason for keeping water in the trap? What is the object of the

vent and how far does it extend? Is this pipe a real necessity? Could it be omitted? Give reason for your answer.

Materials Required.—Ring stand; quart battery jar or other vessel to collect water in; trap as constructed in the sketch.

EXPERIMENT 24

THE PNEUMATIC TANK SYSTEM OF HOUSE WATER SUPPLY

What to do:

(*a*) Arrange apparatus as shown in Fig. 18, taking care to select a bottle of large size (1 qt. or more) and of strong walls, as the pressure would be likely to break a Florence

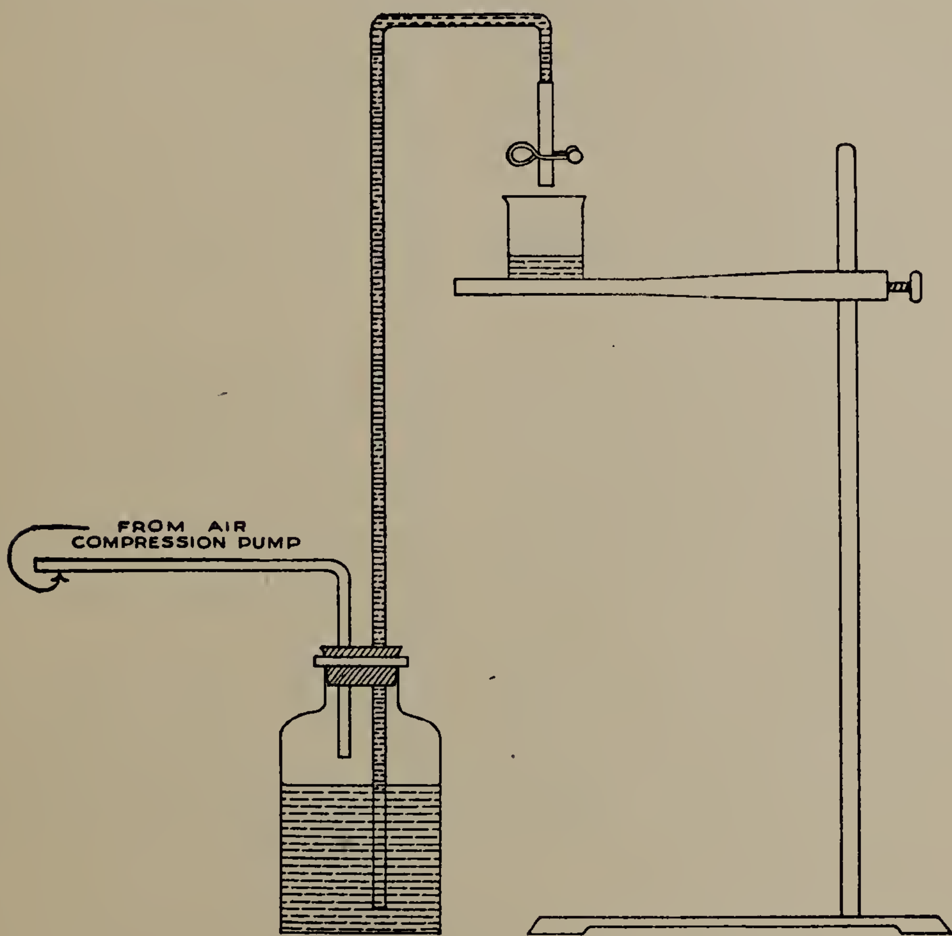


FIG. 18.

flask. An ordinary bicycle pump is excellent for production of air pressure. See that all fittings are air-tight.

(*b*) Start pumping slowly—a single full stroke may produce ample pressure. Test by opening the pinch-cock

to see whether the water gushes into the receiving cup, or not. If so, let it continue to run till it stops from an equalizing of pressures.

(*c*) Pump another stroke or more as need may be, producing a stronger pressure on water surface than before. Test pressure by momentarily opening pinch-cock. Would there be any difference in the amount of pressure secured in case the water (instead of the air) were forced in by the pump? In actual house service, water is forced in and compresses the confined air. The air-compression pump is used in this experiment for the sake of convenience.

(*d*) *Problem.*—Regard the tube *B* as a vertical standpipe of indefinite height without pinch-cock stopper. Remembering that a depth of 2.3 ft. is necessary to produce a downward pressure of 1 lb. per square inch, find the height this tube would be in case the tank pressure were 20 lb. per square inch.

(*e*) In cities the ordinary water main pressure is not sufficient to force water to the top of high buildings. This auxiliary pump system is used in such buildings to maintain water service on all floors. What would be the pump pressure needed to force water to the top of a building 230 ft. high?

Materials Required.—Strong-walled bottle (quart size); 2-hole rubber stopper; glass tubing of about 25 cm. and 75 cm. each; rubber tubing to fit; pinch-cock; ring stand; compression air pump.

EXPERIMENT 25

BOYLE'S LAW

How does the volume of a gas vary with the pressure to which it is subjected? Or, if the volume of the air in a bicycle tube is 1 gal. when the pressure gauge shows 30 lb., what would the volume become if all the tension on the air due to the enclosing tube should be suddenly released?

PART I—THE J-TUBE METHOD

Introductory.—The time-honored apparatus for testing Boyle's law consists of a glass J-tube closed at the shorter end, and usually terminating at the upper open end in a funnel to facilitate the pouring of mercury into it. From the bend in the glass the distance to the short end and to the upper end should be not less than 20 and 100 cm. respectively. Fastened to the upright frame between the two parallel tubes is a meter stick to facilitate measurements.

What to do:

(*a*) First pour enough mercury into the tube to confine the air in the closed end without compressing it. This latter fact may be known by noting whether or not the levels of mercury in the two tubes stand at the same height. Note and record the level of the mercury in the short tube.

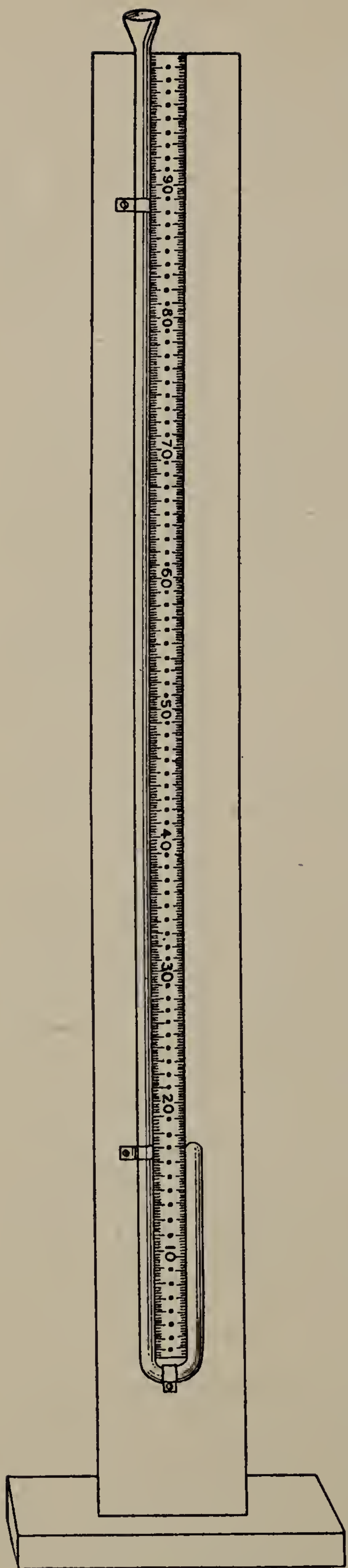


FIG. 19.

(*b*) Note and record the height of the barometer column.

(*c*) Pour more mercury in till the difference in levels between the two columns is, say, 10 cm. The total pressure on the air in the tube is now the sum of this difference in levels and the observed barometer column. Note and record this sum.

(*d*) Observe the length of the air column in the shorter end. If we assume that the bore of the tube is uniform from end to end, then the shortened length of air column just observed corresponds to the shrinkage in volume due to the increased pressure to which the air is subjected. If the column secured in paragraph (*a*) be taken as, say, 20 cm. in length, and the observed length now is, say, 19 cm., then the volume has shrunk from $\frac{20}{20}$ to $\frac{19}{20}$ of its original volume.

(*e*) Pour in more mercury till the difference in levels is, say, 20 cm. Note and record pressure and volume as before. Continue tests and records till the difference in levels is the same as the observed barometer height.

(*f*) Record results in the following form:

Barometer reading = ... mm.
Date..........
Hour..........

Test	Length of air column	Relative volume	Difference in mercury levels	Total pressure	Pressure times volume
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

(*g*) Do you find the products of the volumes and pressures approximately equal? To what errors do you believe the discrepancies are due?

(*h*) Plot a graph using your volume readings as abscissas, and your pressure readings as ordinates.

Ahrens' Method

Set up the apparatus as shown in the cut. This apparatus consists chiefly of a gauge glass sealed at the upper end which has confined in it a quantity of air by means of an oil seal. This gauge glass is connected to a reservoir of larger volume, which should contain about 3 pt. of oil. It is fitted with a stop-cock at the upper end. A pressure gauge is connected by suitable fittings between the reservoir and the gauge glass and indicates the

pressure on the confined air at all times. In order to read the volumes of gas confined under different pressures a meter stick is fastened next to the gauge glass and reads from the top down.

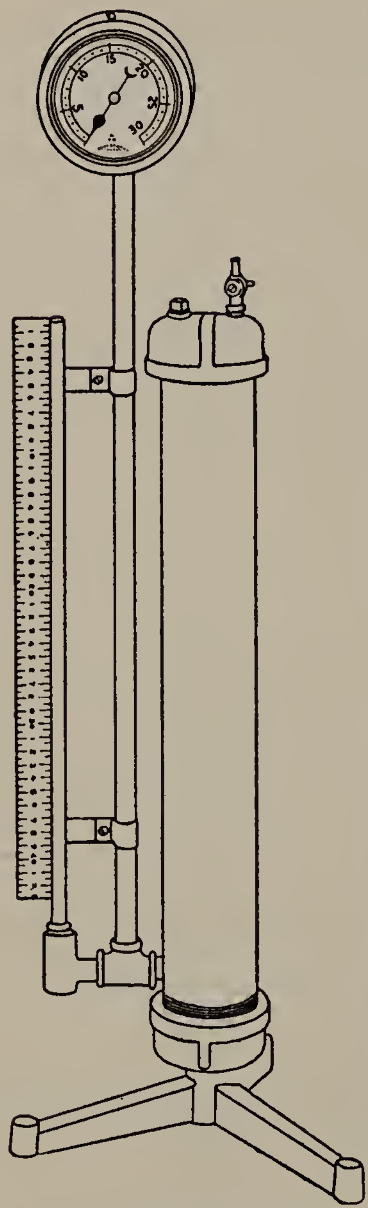


FIG. 20.

What to do:

(*a*) Make note of the height of the column of air in the gauge glass when the stop-cock on the reservoir is open, that is at atmospheric pressure. This reading will be the volume of the air provided we assume the tube to be of uniform bore.

Now by means of a bicycle pump or other source of air pressure, pump air into the reservoir until the pressure gauge reads nearly up to its full capacity, or until the volume of the confined air is about one-third of its original volume. Close the stop-cock and make note of the volume of air and also the gauge reading. Now, by opening the stop-cock slightly release a little air, again make note of the volume of air and the gauge reading. Repeat this operation until you have obtained at least ten results and record them in the following form:

Increasing values			Decreasing values		
Gauge reading P	Volume V	Pressure × volume	Gauge reading P	Volume V	Pressure × volume

(*b*) Repeat the experiment by increasing the pressures slowly instead of decreasing them. Start with a small gauge reading *not zero.*

(*c*) Using the results you have just obtained plot a curve on cross-section paper showing the relationship between pressures and volumes. Use pressures as ordinates and volumes as abscissas.

Materials Required.—One Boyle's law apparatus and a bicycle pump or other source of air pressure.

NOTE TO INSTRUCTOR.—It will be found that by using inverse values the curve will become a straight line.

The apparatus can be secured from the Central Scientific Company of Chicago.

To prepare for use place about 3 pt. of light lubricating oil in the reservoir. Turn the apparatus over on its side with the gauge glass on the under side so that some of the confined air will be replaced by oil. Now set right side up again. The oil should rise in the gauge glass to a point near the center of the scale. The gauge should read atmospheric pressure (14.6) to begin with.

EXPERIMENT 26

HOOKE'S LAW

If a spiral spring stretches 1 in. under a load of 50 lb., will it stretch 2 in. under a load of 100 lb.?

The spring balance consists of a spiral spring one end of which is rigidly attached to the casing or ring, the other end having a draw-bar which extends out beyond the casing, and carries a hook. Attached to the same end of the spring is a pointed index, which emerges through the casing in a longitudinal slit, and runs parallel to the scale shown on one or both sides.

What to do:

Hang the spring balance upright to some firm support. Does the index point to zero? It should, but frequently does not because at some time the spring has been left on tension for a long time and on release failed to return to its original form, so is now "deformed."

Measure in millimeters the distance on the scale from zero to the point of greatest elongation. Now suspend a 500-gram weight from the balance hook. Note and record the point at which the index comes to rest. Make other tests, recording results as follows:

Load	Scale reading	Elongation in mm.	Elongation per 100 grams
500			
700			
800			
1,000			
1,100			
1,200			
1,500			
1,700			
1,800			
2,000			

Using loads as ordinates and elongations as abscissas, plot a graph showing the relation of the loads to the stretchings. Is the stretching of the spring proportional to the load carried?

Materials Required.—Spring balance; weights; cross-section paper.

EXPERIMENT 27

COMPRESSION OF A SPRING

If a shock absorber spring is supporting a certain load and you double the load, what of the amount of compression?

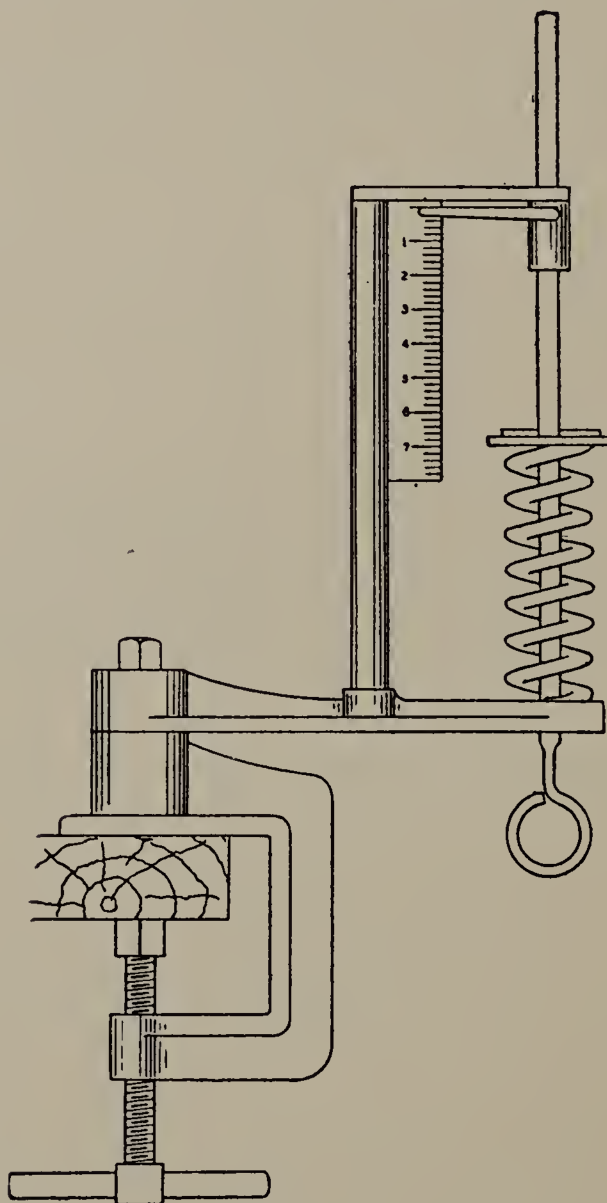


FIG. 21.

When the spring rebounds does the force continue the same until the rebound is complete?

What to do:

(*a*) Set up a spring compression apparatus as shown in Fig. 21. A poppet valve spring may be used for the test. Take the reading on the centimeter scale. This reading should be the length of the spring. Hang a load of 500 grams on the rod which passes through the spring and again take the reading. Add 500 grams and again take the reading. Continue the readings adding 500 grams each time until the spring is closed.

(*b*) Plot a graph letting abscissas represent the load and ordinates the length of the spring.

Does Hooke's law apply perfectly throughout all the tests? If not what variations from Hooke's law do you find?

Answer the questions asked at the beginning of the experiment.

Materials Required.—Spring compression apparatus; poppet valve spring for testing; weights.

EXPERIMENT 28

CENTER OF GRAVITY

If an object is unequally weighted at the ends, is the center of gravity at the center of the object?

Why should the center of gravity of a rotating wheel, say a driving wheel of a locomotive or a balance wheel, be in the axis?

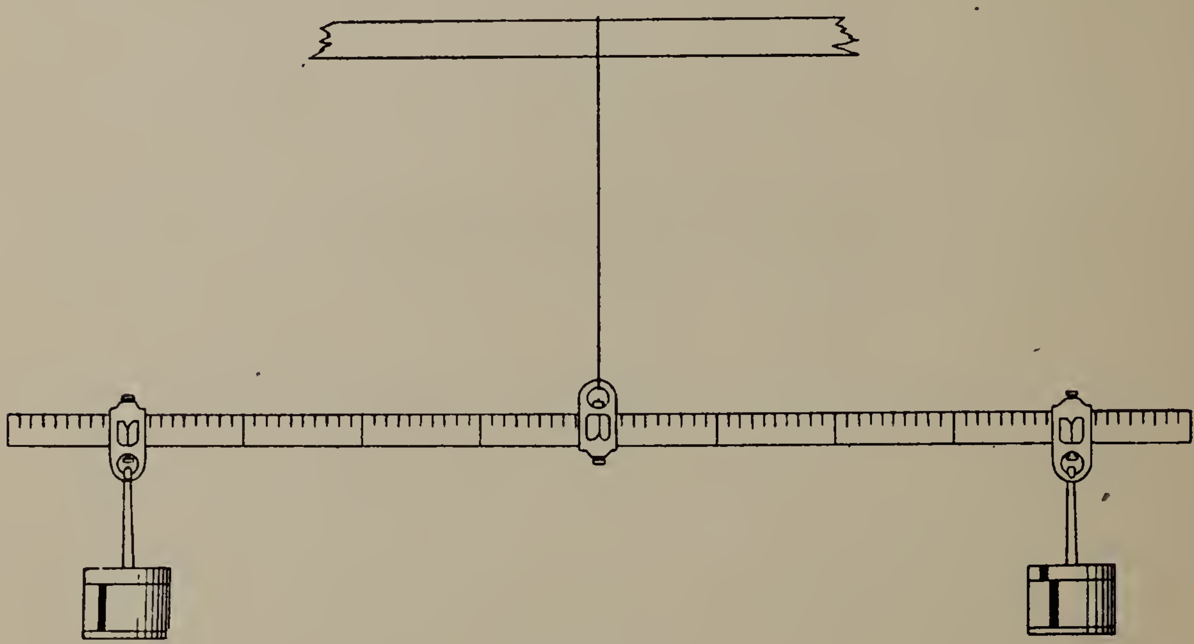


FIG. 22.

What to do:

(*a*) Arrange a meter stick and lever clamps so that weights can be suspended by two clamps from the 10-cm. and the 90-cm. marks. The meter stick rests on edge in a third clamp which serves as the fulcrum (see Fig. 22). Suspend from the 10-cm. mark a 500-gram weight and from the 90-cm. mark a 1,000-gram weight. With the weights thus suspended move the meter stick along in the

middle clamp until it is balanced. The center of gravity of meter stick and weights is then directly over the middle clamp. How far is the center of gravity from the 1,000-gram weight? How far from the 500-gram weight? How do these distances compare with the weights themselves? Can you state this relation in the form of a proportion? Are the distances directly or inversely proportional to the weights?

The proportion will not be exactly true on account of the weight of the meter stick but the weight of the meter stick is small compared with the suspended weights.

(*b*) Support by means of its axis a small wheel which is well balanced so that it turns very easily. Give the wheel a quick turn and note the time it continues spinning when undisturbed. Now attach a weight, equal to about a tenth of the weight of the wheel, to the rim. Give the wheel a quick turn as before. Does it come to rest in a shorter time or does it spin longer than at first? How was the center of gravity changed by adding the weight? Does this account for the result? Now attach to the rim a second weight equal to the first and on the opposite side of the axis so as to counterbalance the first weight. Where is the center of gravity now? Again spin the wheel. Note the time as before. Explain the result. Where should the center of gravity of a balance wheel be? Why?

When you have opportunity observe the driving wheel of a locomotive and report what you observe.

Materials Required.—Meter stick; level clamps; weights; wheel well balanced on its axis (a pulley 4 in. or more in diameter well fitted on a shaft may be used or the pupil may make the second test out of class with his bicycle).

EXPERIMENT 29

THE PRINCIPLE OF MOMENTS

If two boys carry a load between them on a pole, what portion of the load does each boy carry?

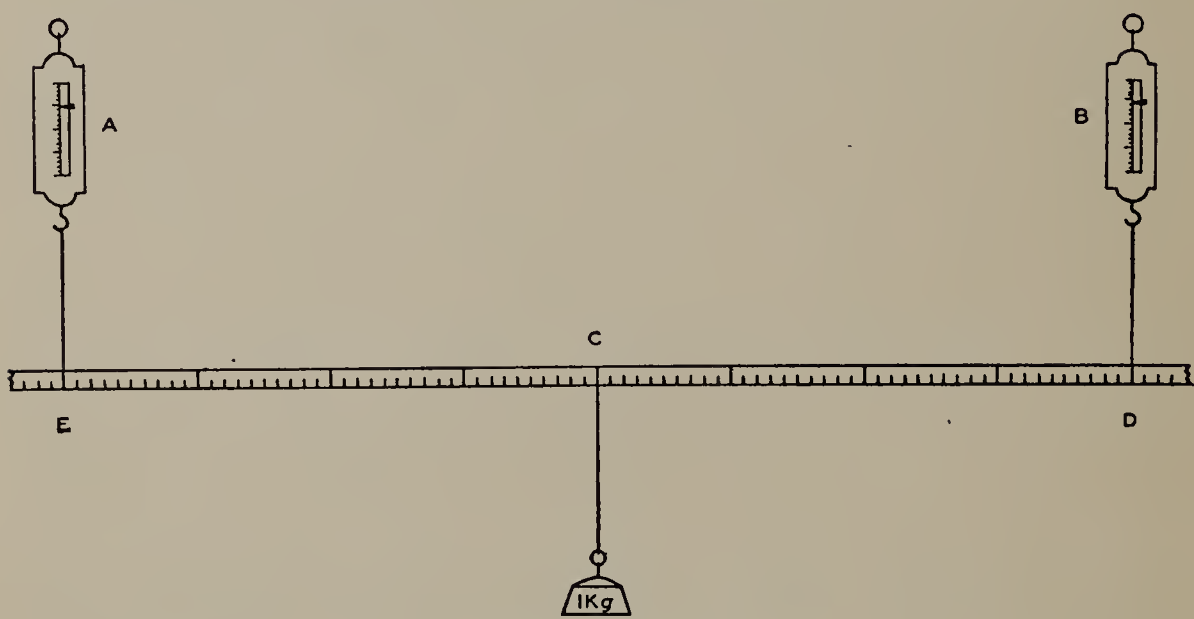


FIG. 23.

What to do:

(*a*) Attach a meter stick by loops of string to two spring balances, *A* and *B*, on the 10- and 90-cm. lines respectively. Note and record the readings of balances *A* and *B*. Since these readings represent the weight of the meter stick, a correction equal to these readings must be subtracted when any additional load is carried by the stick if one wants to get the net weight of the load (see Fig. 23).

(*b*) Now on the 50-cm. line load the stick with some known weight, say 1 kg. Note and record the readings, making corrections for weight of stick as described above.

How does the sum of the corrected readings compare with the load carried at *C*?

(*c*) The tendency of the force *A* acting on the rod at *E* is to make it rotate about the point *C* clockwise; while the tendency of the force *B* acting on the rod at *D* is to make it rotate about the point *C*, counter-clockwise. The tendency to rotate about a point is known as a moment, the clockwise tendency being called positive and the counter-clockwise tendency being called negative. This tendency is measured by the product of the force and the distance from that fixed point. How do these two moments compare as determined from paragraph (*b*)?

(*d*) Now move the load to the 30-cm. line. Note and record readings, apparent and corrected, as before. How does the sum of the corrected readings compare with the load? State a proportion found true in both paragraphs (*b*) and (*c*).

(*e*) Make three other tests, placing the load on (say) the 25-, the 60- and the 40-cm. lines respectively. Record results in the following form:

Test	*EC*	*CD*	Readings					Moments	
			Balance *A*		Balance *B*		Sum of corrected	+	−
			Apparent	Corrected	Apparent	Corrected			
1									
2									
3									
4									
5									

(*f*) Are the moments theoretically equal? Are they practically? Give reasons showing why, in practice, they are usually unequal.

Problem.—If the two boys mentioned at the beginning of this experiment carry a load of 50 lb. between them on a pole 10 ft. long, where should the load be hung in order that one should carry 30 lb., the other 20 lb.? Prove your answer by statement of a proportion.

Materials Required.—Two spring balances; meter stick; weight of 1 or 2 kg.; cord.

EXPERIMENT 30

LEVER OF THE FIRST CLASS

Can a boy with a crowbar lift a weight more or less easily than he can without the bar?

What to do:

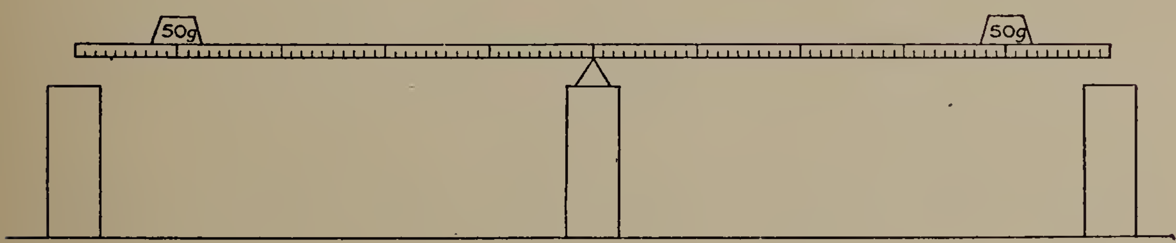


FIG. 24.

Balance the meter stick on the prism as shown in Fig. 24. Placing a 50-gram weight on the 10-cm. line, find the point of the stick on which another 50-gram will balance the bar, either end remaining down when put down. Call the weight on the right side of the prism the force (F), and the other the load (L). The tendency of the force to make the bar rotate about the fulcrum (prism) in a clockwise direction is known as a positive moment; and the tendency of the weight to make the bar rotate in a counter-clockwise direction is known as a negative moment. Either one is represented by the product of the force (or weight) and the distance from the fulcrum.

Make other tests, tabulating results as follows:

Table 1

Trial	*F*	*L*	*Fd*	*Ld*	Positive moment	Negative moment	Sum
1	50	50	40				
2	100	100	...	30			
3	100	500	40				
4	500	100	...	40			
5	50	...	40	10			

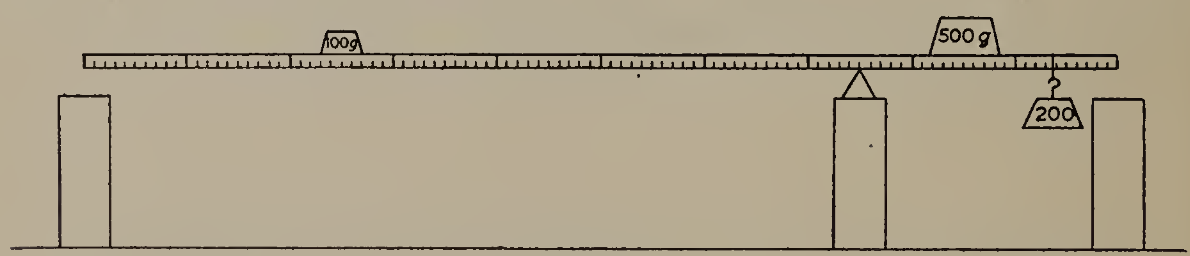


Fig. 25.

Now shift the stick along till the 25-cm. line is over the fulcrum. Take some counterweight (say, 200 grams) and suspend by a cord below the stick (see Fig. 25) on the short arm of the lever, shifting along till lever is balanced. Now put a 500-gram weight on the 15-cm. line, and balance by a 100-gram weight on the other end.

Make other tests, tabulating results as follows:

Table 2

Trial	*F*	*L*	*Fd*	*Ld*	Positive moment	Negative moment	Sum
1	100	500	...	10			
2	100	500	...	14			
3	100	500	...	7			
4	100	500	...	5			

Give some familiar examples of levers of the first class.

Materials Required.—Meter stick; one wooden prism, three pillars, say 2 by 2 by 6 in. for support of fulcrum and stops; set of weights.

EXPERIMENT 31

LEVER OF THE SECOND CLASS

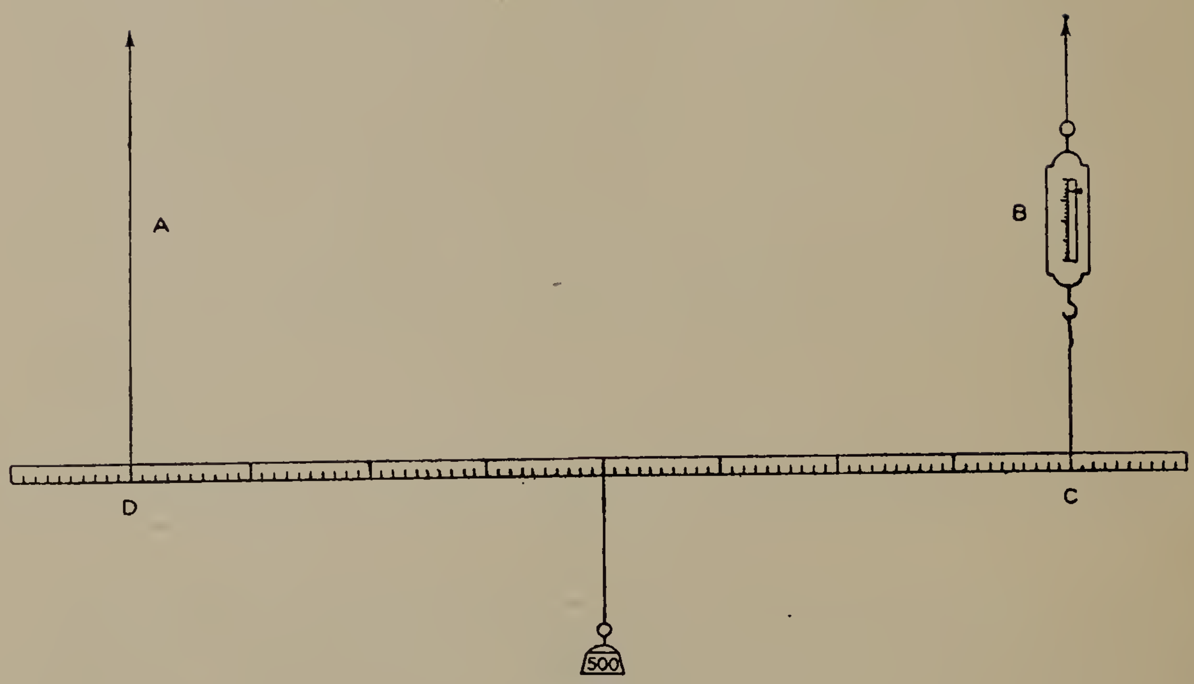


FIG. 26.

Arrange the apparatus as shown in Fig. 26, being careful to see that the stick is horizontal. In this form of the experiment, the first point to see is that the string *A* supporting the stick at *D* now takes the place of the usual prism in lever experiments, and marks the location of the fulcrum. With the stick arranged as shown, of course, the spring balance *B* carries one-half the weight of the stick, and in subsequent readings of the balance allowance must be made for this stick weight.

What to do:

By a looped string now hang a load of 1000 grams on stick on 50-cm. line. Compute the force and load moments, and compare, remembering (1) to make allowance as described above, and (2) to regard the force arm

as the distance *CD*. Make other tests, tabulating results as follows:

TABLE I

Trial	F = balance reading		Load	*Fd*	*Ld*	Positive moment	Negative moment	Sum
	Apparent	Corrected						
1			1,000	80	40			
2			1,000	80	30			
3			1,000	80	20			
4			1,000	80	10			

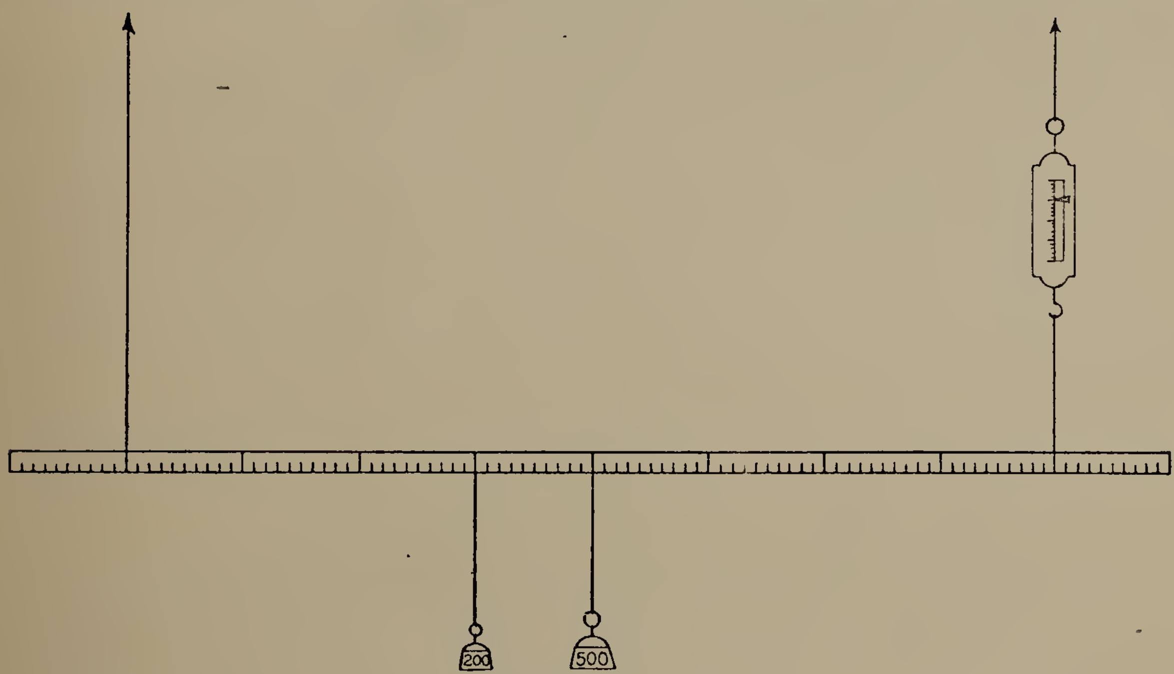


FIG. 27.

Supposing two loads be placed on the stick at different points, how are the moments computed? Arrange apparatus as shown in Fig. 27 and proceed as follows:

Compute the force moment as before. Then compute separately the two load moments, and take their sum, which should equal the force moment. Tabulate as follows:

TABLE 2

Trial	F = balance reading		$Load_1$	$Load_2$	Fd	Ld_1	Ld_2	Positive moment	Negative moment	Sum
	Apparent	Corrected								
1			500	200	80	40	30			
2			500	200	80	50	20			
3			500	200	80	60	10			
4			500	200	80	70	5			

Give several familiar examples of levers of the second class.

Materials Required.—Meter stick; cord; spring balance; one 500-gram and one 200-gram weight.

EXPERIMENT 32

LEVER OF THE THIRD CLASS

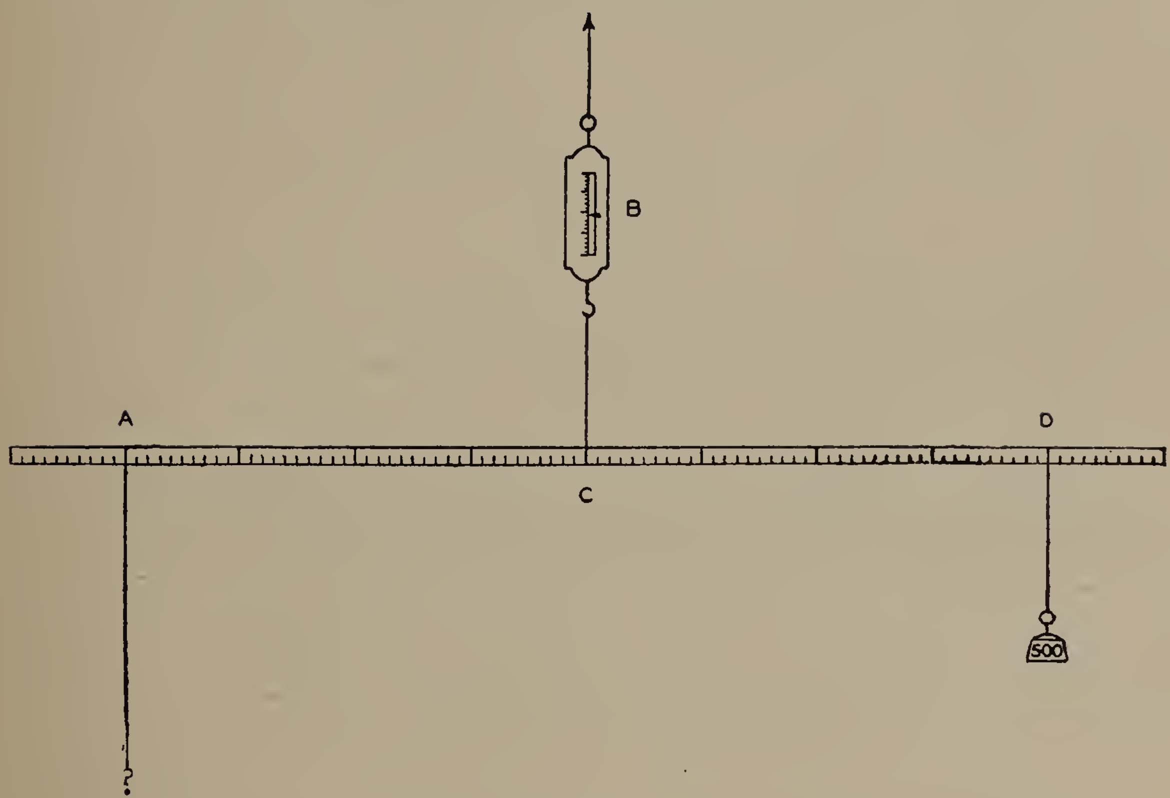


FIG. 28.

Does any form of lever require more force than the weight of the load?

What to do:

Suspend the meter stick at its center of mass by a cord attached to spring balance as shown in Fig. 28. By a cord attach left-hand end to hook in table so as to leave the bar in horizontal position. Note the index reading showing weight of stick, and record it.

Fasten a 500-gram weight to right-hand end 10 cm. from the end. Note the reading of the spring balance, and record it. Compute the force and load moments,

remembering that the fulcrum is now at A, the force distance CA, and the load distance DA. Make other tests, tabulating results as follows:

Allowance for weight of stick

Test	Balance reading		Load	*Fd*	*Ld*	Positive moment	Negative moment	Sum
	Apparent	Corrected						
1			500	40	80			
2			500	40	70			
3			500	40	60			
4			700	40	80			

Materials Required.—Meter stick; spring balance; cord; screw hook; one 500-gram and one 200-gram weight.

EXPERIMENT 33

INFLUENCE OF THE WEIGHT OF THE LEVER

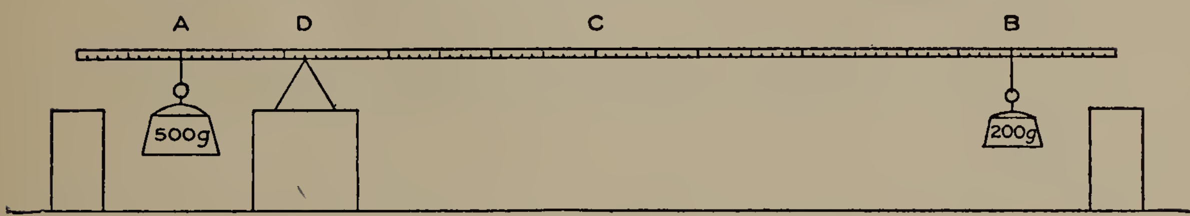


FIG. 29.

In experiments with the lever (unles counterweighted), what allowance should be made for the weight of the lever itself?

What to do:

(*a*) In a straight line set up three pillars (4 by 2 by 2 in.) about 45 cm. apart, placing a prism on the center one. Balance meter stick on the prism. In this way determine the center of mass to within a millimeter, and mark the point *C*.

(*b*) Now by a string hang a 500-gram weight at one end on the 90-cm. line, and a 200-gram weight at the other end on the 10-cm. line. Adjust the stick till a nice balance is obtained. Note and record the new center of mass (*D*).

(*c*) The center of mass may be defined as the point about which the entire weight of the stick balances. We determined this point in the stick in paragraph (*a*) as *C*. When a new balance for the stick was found in paragraph (*b*), the original center of mass was between the fulcrum and the smaller weight. In other words, the entire weight of the stick was acting on the side of the smaller weight, its arm being the distance *C* to *D*. Note and record this distance. The moments may now be calculated as follows:

$500 . AD = (200 . BD) + (CD . x)$, where x = the weight of the stick. When you have solved for x, check your result by weighing the stick.

Make other tests recording results as follows:

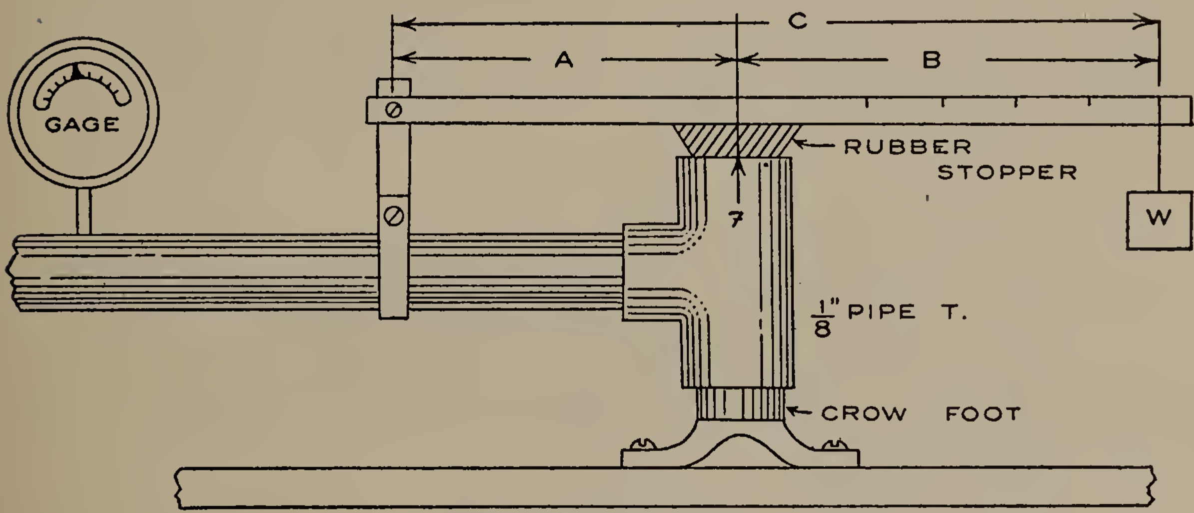
W	F	WD	FD	CD	Weight of stick	
					As computed	As measured
500	200					
500	100					
200	100					

Materials Required.—Meter stick; wooden prism; three pillars 4 by 2 by 2 in. 500-gram and 200-gram and 100-gram weights; string; balances.

EXPERIMENT 34

THE SAFETY VALVE

Where are safety valves used and why?



THE SAFETY VALVE

FIG. 30.

What to do:

(*a*) Secure or construct a safety valve similar to that shown in Fig. 30. Attach a rubber tube to the open end so that you can blow through it or so that it might be connected to a water, steam, or air line.

(*b*) Measure carefully the diameter of the opening into which the rubber stopper fits. Calculate the area of this opening.

(*c*) Now adjust the weight so that it rests in the notch nearest the stopper. Make note of the weight used and also the lengths of the members *A*, *B*, and *C*. Now open the supply valve until steam escapes freely around the stopper. Note whether the stopper opened slowly or rather suddenly. Record all results in tabular form.

From your knowledge of levers calculate the force required to raise the stopper. From this value and the area of the opening you can find the pressure per unit area or better the pressure in pounds per square inch on the stopper. Compare this pressure with steam gauge reading.

Pressure = force ÷ area.

Test	Lengths			W	F	Pressures		
	A	B	C			Calculated	Gauge	Difference

(*d*) Repeat the experiment, keeping arm A constant and placing W at different distances from the hinge. Try also various weights.

INSTRUCTOR'S NOTE.—If only one gauge is available, this can be placed in the main supply line and any number of students can work the experiment and refer to the gauge. If the rubber stopper shows any signs of wedging, a flat leather washer which covers the top of the opening can be used in place of the stopper.

The position of the clamp and the size of the weight will depend upon the source of energy and the pressure available. If neither steam nor air is at hand, the apparatus can be connected to the watter supply. However, if this is done, there is only a limited range of rather small values. Steam or air is prefered. The apparatus can be constructed of any size fittings.

Materials Required.—One crow-foot, pipe T; short piece of pipe; rubber stopper; pressure gauge; clamp with bolts; wood lever about 15 in. long; a weight; source of pressure such as steam, air, or water.

EXPERIMENT 35

WHIFFLETREES

Introductory Discussion.—Whiffletrees are an application of the principle of moments. When two horses are used, the problem is simple. The two horses pull at points equally distant from the center. When three horses

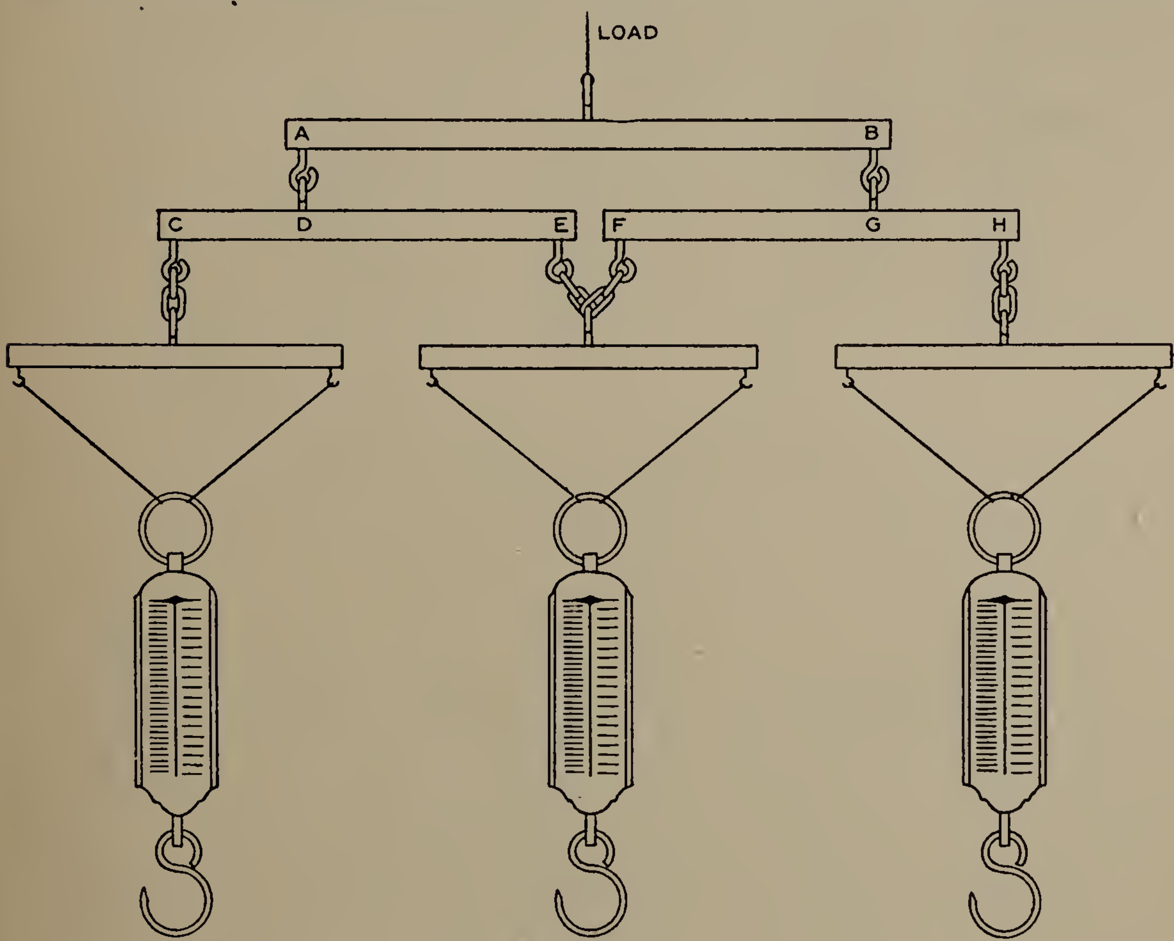


FIG. 31.

are used the problem is not so simple. How can the whiffletrees be arranged so that each horse will pull one-third of the load?

What to do:

(*a*) Arrange the small whiffletrees as shown in Fig. 31,

where the three spring balances which pull in the same direction represent three horses and a fourth balance or a weight acts as the load. Compare the two moments that tend to turn CE about the point D; also the two moments tending to turn FH about the point G. How does the pull at F compare with the pull at H? How does the pull at E compare with the pull at C? Why does the center horse pull with the same force as each of the other two?

Materials Required.—Spring balances; small whiffletrees which may be easily made by the pupil merely by connecting sticks with strong cord or small chains and screw-hooks, using the relative dimensions shown in Fig. 31 in which $DE = 2CD$ and $FG = 2GH$. Twelve inches would be a convenient length for CE.

EXPERIMENT 36

PULLEYS

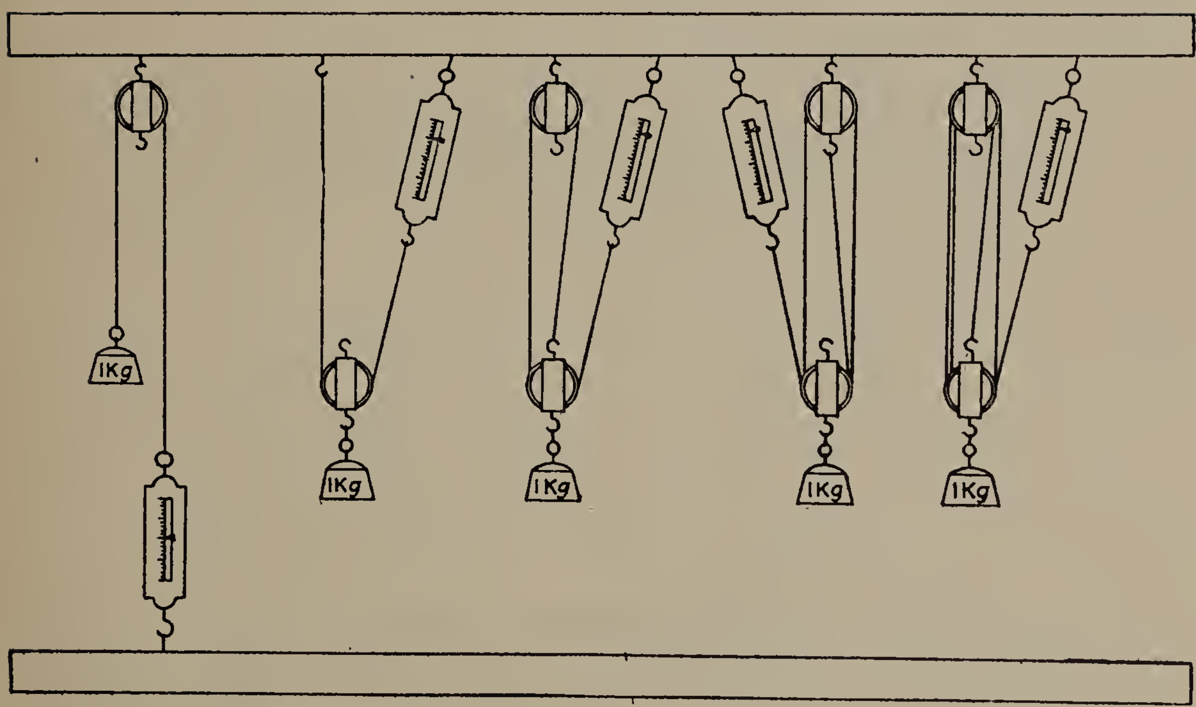


Fig. 32.

What to do:

(*a*) Weigh the spring balance, remembering it is to be part of the force. Suspend the weight by the cord, as shown in Fig. 32, tying the cord to the ring of the spring balance, and counterweighting by holding the hook of the spring balance by the thumb. In getting the total force necessary to counterweight, remember to add to the balance reading, the weight of the spring balance (test one only). In all other cases hang the cord to the hook and support the balance by the ring.

(*b*) To find the mechanical advantage, it is necessary to find the ratio of force-distance to load-distance. To

lift the load 20 cm. requires the force to move how far? Test for each case.

(*c*) *Efficiency* is the ratio of output to input. As applied to pulleys,

$$\text{Efficiency} = \frac{\text{Load} \times \text{load-distance}}{\text{Force} \times \text{force-distance}}.$$

From the values obtained in (*a*) and (*b*) above compute the efficiency in each of the five cases. Tabulate results as follows:

Trial	Load	Force	Load distance	Force distance	Number cords supporting loads	Mechanical advantage	Efficiency
1			20				
2			20				
3			20				
4			20				
5			20				

(*d*) On account of the stiffness of the ropes and the friction of the pulleys, the ordinary system gives an efficiency of from 40 to 90 per cent. On the latter basis, what load would a force of 100 lb. raise in case 3 above?

(*e*) What relation exists between the number of cords employed to hold the weight and the mechanical advantage secured by the system?

Materials Required.—Cord; spring balance; one single and two double pulleys; weight of 1 or 2 kg.

EXPERIMENT 37

GEARS

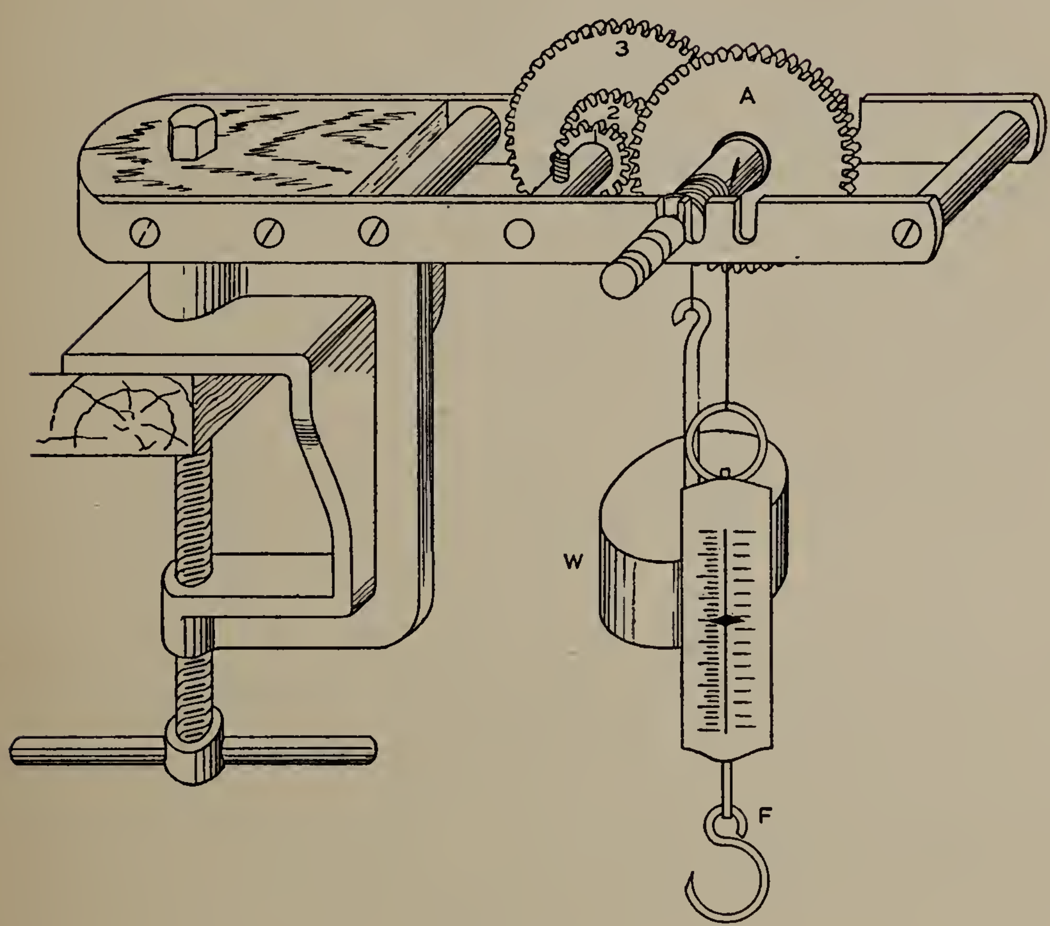


FIG. 33.

For what purposes are gears used? What is the difference between "low gear" and "high gear?" What is meant by gearing up? gearing down? shifting gears? Why does an automobile go up a steep hill on low gear?

What to do:

(*a*) Arrange the train of gears as in Fig. 33. *A* is the driving gear and 1 is the driven gear. Find the pull required to lift the weight using a slow steady pull. Measure the distance through which the pull, *F*, must act to lift

the load, W, 1 ft. Count the teeth on each gear wheel. Compare the ratio of the distances with the ratio of the number of teeth. Also compare these ratios with the ratio of the pull and the load. In this test you have "geared up." This arrangement corresponds to high gear in an automobile transmission.

(*b*) With the same arrangement of gears interchange the force and the weight and repeat the tests. In this test you have "geared down." Gear 1 is the driving gear now, and A is the driven gear.

(*c*) Attach the spring balance and the weight again as in (*a*) and shift the gears until the driving gear A meshes with number 2. A is then the driving gear and 2 is the driven gear. Make the same tests as in (*a*). This is second speed.

(*d*) Shift the gears until the driving gear meshes with number 3 and make the same tests as in (*a*). This is low gear.

In which case can you lift the heaviest load with a given pull? Answer the questions asked in the first paragraph.

Materials Required.—Train of gears as shown in Fig. 33; clamp; spring balance; cord (fish line or Goodyear lock-stitch cord); weights.

EXPERIMENT 38

THE SEWING MACHINE

Introductory Discussion.—The purpose of this experiment is to prepare girls to use the sewing machine with an intelligent understanding of its operation, and incidentally lead to an understanding of the advantages of machines in general. As a result of this study the girls should see the sewing machine as a machine of great economic value and understand that this economic value results from the application of the principles of machines. This comprehensive view of the sewing machine will lead to an intelligent interest in machines in general. To attain this point of view is more important than to make an intensive study of any one of the parts of the machine.

The experiment may be worked in the laboratory, one machine being sufficient for a class, or it may be assigned as a home experiment. If assigned as a home experiment work on the sewing-machine chart in class should precede work on the machine at home.

What to do:

(*a*) After a study of the chart examine your machine and determine to which of the following types it belongs: (1) rotary hook, (2) rotary shuttle, (3) oscillating hook, (4) oscillating shuttle, (5) vibrating shuttle. Find out exactly how the knot is produced. Does the loop which forms the knot pass completely around the hook or shuttle? Could the shuttle be rigidly attached to its carriage?

(*b*) Examine the feeding device and note how the length of the stitch is regulated. What is the length of the

shortest stitch possible? What is the length of the longest stitch possible?

(*c*) How the motion is transmitted. What is the use of the pitman rod which connects the treadle and the drive wheel? How many revolutions does the drive wheel make for one complete vibration of the treadle? What is the use of the belt? Measure the diameter of the drive wheel. Compute its circumference. Determine the circumference of the grooved pulley on the head of the machine over which the belt runs. This pulley is part of the balance wheel. If the belt does not slip, how many revolutions does the balance wheel make for one revolution of the drive wheel? How many stitches are made for one revolution of the balance wheel? How many for one revolution of the drive wheel? How many for one complete vibration of the treadle? Why should the balance wheel be smaller than the drive wheel?

Run the machine for just 30 seconds at the usual rate and let some one count the number of complete vibrations of the treadle. How many stitches per minute do you make?

(*d*) Force. If the experiment is worked in the laboratory make the following test. Place a piece of cloth under the needle and have the needle just ready to enter the cloth. Hold the balance wheel firmly so that the belt will slip and adjust the driving wheel until the crank arm is at right angle with the pitman. Release the balance wheel. Place a box on the treadle about halfway between the pivot and the toe end. Put weights in the box until the needle is pushed through the cloth. What force was required? Try pushing a needle with your fingers through the same piece of cloth. Does it require more or less force than was applied to the treadle? If in doubt about this, lift the box of weights that was on the treadle. Which requires

more force to lift the weights or to push the needle through the cloth? Is the sewing machine used to increase force or to increase speed?

(*e*) Friction. How does the tension operate? When cloth is thick should tension be reduced or increased? Why? Is friction ever of any use? Is friction ever a disadvantage? Why should you oil the bearings of the machine? Why not oil the belt?

(*f*) Write out a list of the advantages of using a sewing machine over sewing by hand.

Materials Required.—Sewing machine; box and weights; chart of sewing machine. The chart may be obtained by teachers without cost, from the secretary of the National Education Association, or Professor J. A. Randall, Chairman N.E.A. Committee on the Improvement of Physics Teaching, Pratt Institute, Brooklyn, New York.

EXPERIMENT 39

THE INCLINED PLANE

Why does the iceman use a plank to slide a 200-lb. cake of ice into the wagon? What is gained by using an inclined plane?

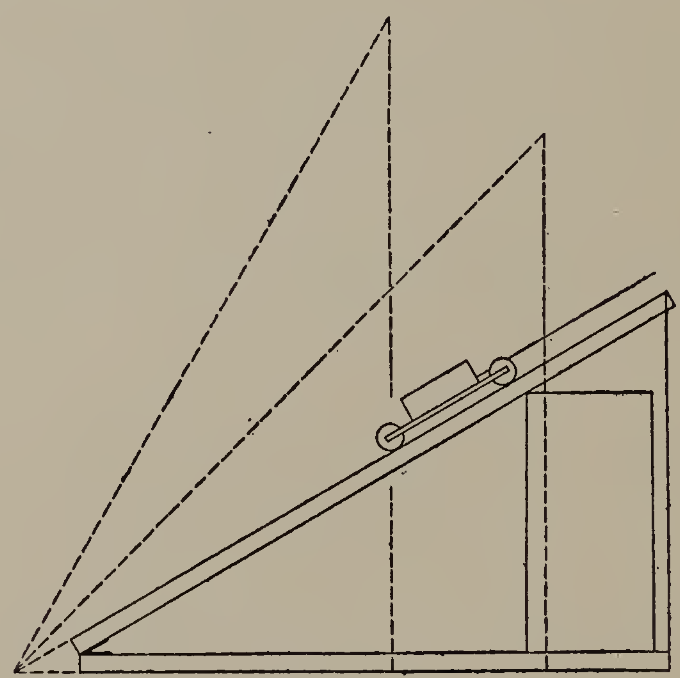


FIG. 34.

What to do:

Arrange board as shown in Fig. 34, tilting it perhaps 30° from the base. The load in this case is to be a cart loaded to weigh two or more kilograms, the wheels moving on bearings having little friction. The force needed to move the load up the incline is to be compared with the total load.

(*b*) In accurate work, allowance should be made for the fact that the spring balance is not vertical, hence but part of the weight of the draw-bar and the hook hangs on

the spring, making the index reading too small. This correction will vary from about 5 grams (when the incline is steepest) to about 30 grams (when most nearly horizontal). In our work we will neglect this correction.

(*c*) To measure the length of the plane, place a meter stick on the upper face of the plane parallel to the sides, letting it slip down till it touches the table. Measure from the point touching the table to upper edge of the incline. To get the height, measure from the upper edge of the incline vertically to the table top.

(*d*) Finally, what is the relation of the output of this machine to the input? This ratio is known as the efficiency and may be stated:

$$\text{Efficiency} = \frac{\text{output}}{\text{input}} = \frac{\text{load} \times \text{height}}{\text{force} \times \text{length}}$$

Make five tests at five different angles of the incline to the base, tabulating results as follows:

Load =				
Trial	Length	Height	Force	Efficiency
1				
2				
3				
4				
5				

Materials Required.—Smooth board 1 by 10 by 40 in.; inclined plane car; spring balance; cord.

EXPERIMENT 40

FORCES ACTING TOGETHER AT ONE POINT

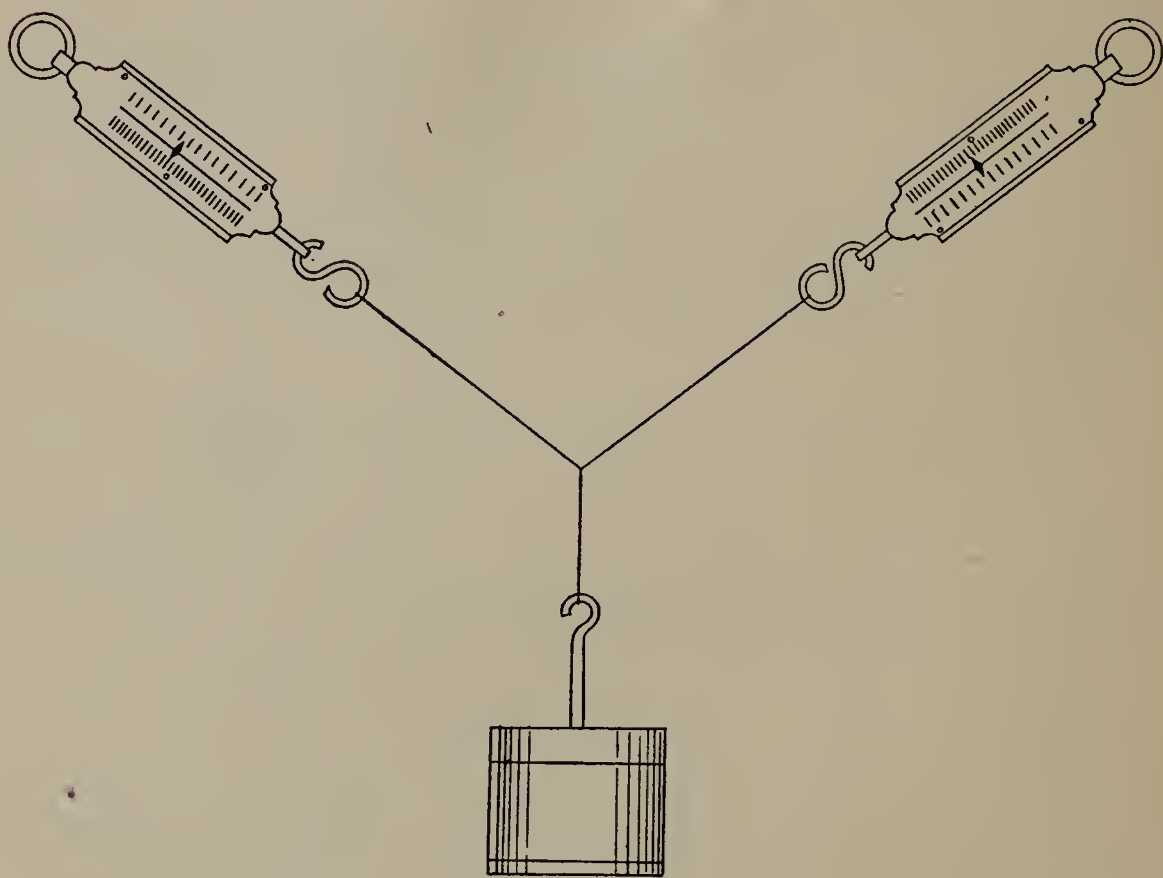


FIG. 35.

If a rope is fastened horizontally to two supports and a weight is hung on the rope, is the pull on the rope equal to the weight? If not, how does the pull compare with the weight?

What to do:

(*a*) Connect the hooks of two spring balances by a cord. Attach the rings of the balances to supports so that the balances are held in a nearly horizontal position. See if the balances indicate zero. If not, take the readings. Now tie a second cord to the first cord at any point be-

tween the spring balances and attach a weight, say, 1,000 grams, to the second cord (see Fig. 35). Read the balances and subtract the first reading to get the forces that are actually supporting the weight. Are these forces each greater or less than the weight? Is their sum greater or less than the weight?

(*b*) To find out still more about these forces, hold a sheet of your notebook paper back of the cords and draw

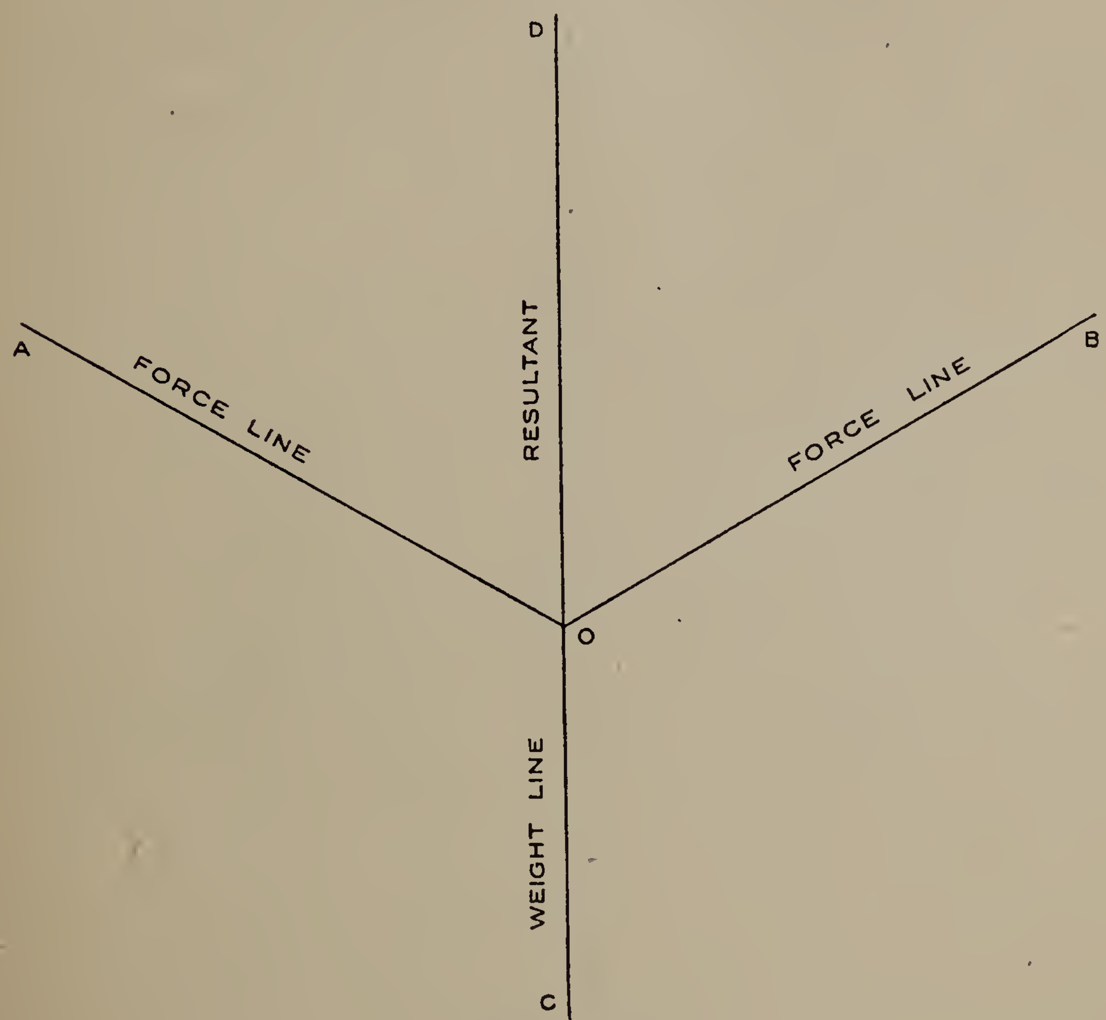


FIG. 36.

three lines, one line exactly back of each cord. You then have a projection of the cords on your paper. From the point where the three lines meet measure on the lower line a distance to represent the weight. For example, let 1 cm. represent 100 grams and, if the weight is 1,000 grams, measure off 10 cm. Mark this distance. Using

the same scale measure on each of the upper lines a distance representing the force acting along that line. You now have three lines representing the three forces. Let us call the lower line the weight line and the other two the force lines. Now from the point at which the lines meet continue the weight line upward and measure on this new line a distance equal to the weight line.

We shall call this line the resultant (see Fig. 36). The resultant represents an upward force which would support the weight. In other words this resultant would do the same thing that the two forces are doing. The two forces represented by the force lines are called the component forces. Connect the end of the resultant line with the ends of the two force lines. What kind of figure have you? What figure represents the relation between two forces and their resultant? Which line in such a figure represents the resultant? Answer the question asked at the beginning of the experiment.

(*c*) Make a second test using a different angle. The cord may be drawn more tightly than at first or not so tight, thus changing the angle between the force lines.

Materials Required.—Spring balances; cord; weight.

EXPERIMENT 41

CRANE STRESSES

Where are cranes used and why are they better for some classes of work than different types of machines?

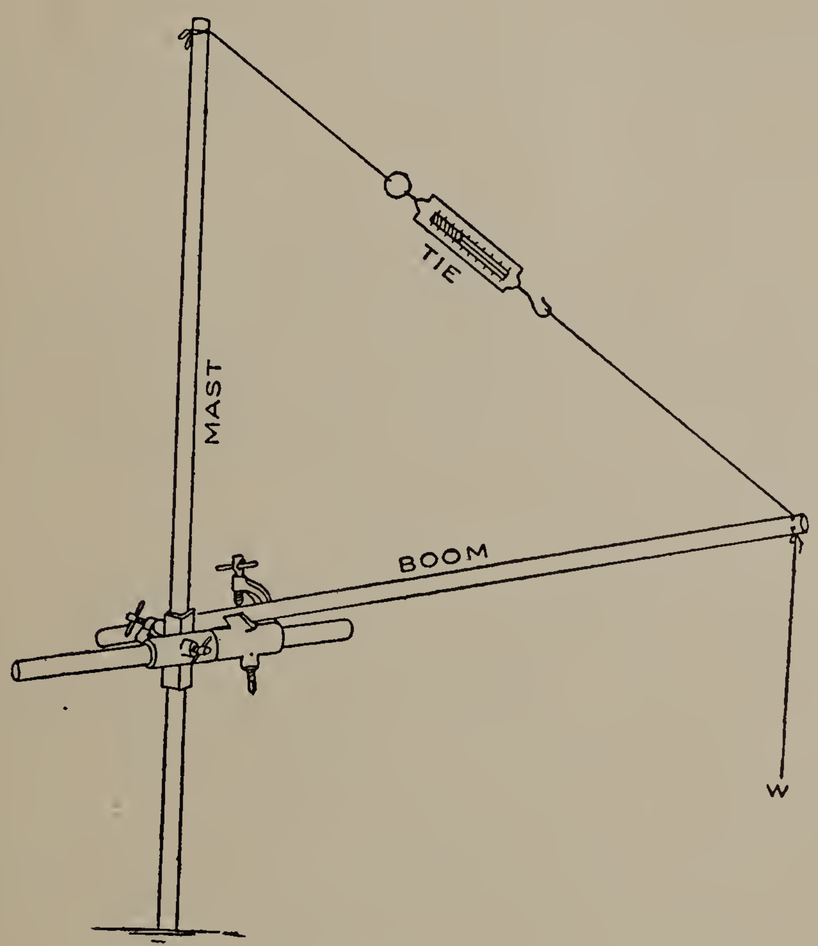


FIG. 37.

What to do:

(*a*) Set up a crane similar to that shown in the sketch using the rods commonly used as supports in the laboratory. The object of the experiment is to show that the forces acting in the members of a simple crane are proportional to their lengths, and to represent these relationships by means of graphs.

(*b*) Keep the boom horizontal and find the stress in the different members for cases in which the angle between the tie and the boom is 15°, 30°, 60°, and 45° respectively.

(*c*) With any given load, make careful note of the lengths of the members and observe the pull in the tie. Record your results in the following table:

Boom angle	Measured			Observed		Calculated	
	Boom	Tie	Mast	Pull	Load	Pull	Push
15°							
30°							
60°							
45°							

From the values just determined plot graphs showing the relation existing between the lengths of the members and the forces in them, for each of the given conditions. Draw all of these graphs to scale.

NOTE.—To determine the pull in the tie, insert an ordinary spring balance. Be sure that the crane moves *very* freely at the boom and mast joint. The weight of the rod will cause the spring balance to read without having applied a load. Make note of this reading and call it your zero reading.

In the case of the small angles the weight of the protruding end of the rod must be compensated for by clamping a small weight on the opposite side of the point of support.

EXPERIMENT 42

A ROOF TRUSS

What must be done to prevent the timbers of a peaked roof from spreading? How does the force which tends to spread the roof compare with the weight supported at the peak of the roof?

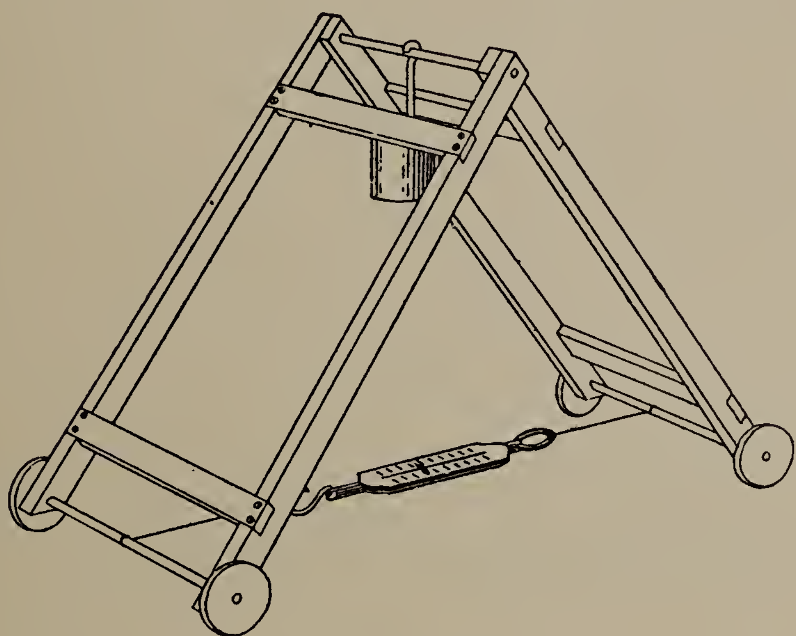


FIG. 38.

What to do:

(*a*) Set up a simple model of a pair of roof trusses as shown in Fig. 38. A weight is to be suspended from the rod at the peak of the truss. Make the angle at the peak 90°. This can be done by using a try square or a T-square, if either is at hand, or by simply holding up a book so that the corner of the book is at the top of the peak and the timbers are in line with the edges of the book. The cord attached to the spring balance can be drawn tighter or

made looser as may be necessary in adjusting the angle. The spring balance is connected in the tie to measure the spreading force. Take the spring-balance reading, the weight not being on the rod.

(*b*) Now put the weight on the rod. Adjust the tie again until the angle at the peak is 90°. Take the reading of the balance. The difference between this reading and

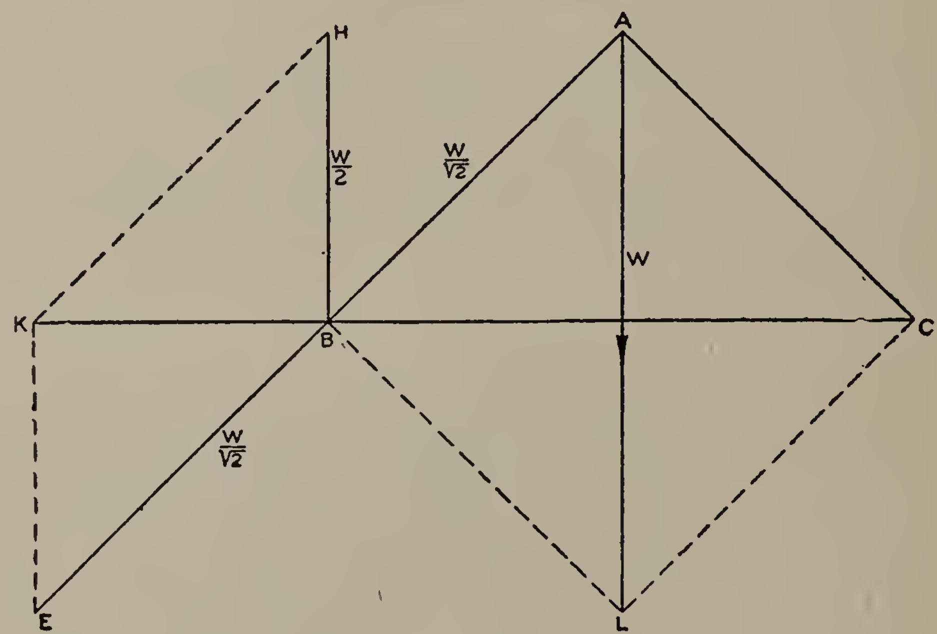


FIG. 39.

the reading obtained in paragraph (*a*) is the corrected reading and shows the spreading force due to the load. How does this corrected balance reading compare with the load *W*?

(*c*) Draw a figure representing the forces like Fig. 39. *AL* represents the weight. *AB* and *AC* respectively represent the push of the two parts of the truss that is the forces acting along the lines *AB* and *AC*. In other words, these two forces are the components of the weight. The weight or load is equivalent to two forces acting along the timbers which form the truss and each equal to $\frac{W}{\sqrt{2}}$. Show from the figure that if $AL = W$, $AB = \frac{W}{\sqrt{2}}$. Now since

the weight is supported at two points, B and C, one-half the weight must be supported at each of these points just as if W were hung on the middle of a rod connecting B and C. This force at B is represented by BH. It is an upward force supporting half the load and hence equal to half the load. The forces acting at the point B are the following: an upward force equal to one-half the load represented by BH, the diagonal thrust acting along AB represented by BE and equal to $\frac{W}{\sqrt{2}}$, the sidewise thrust or spreading force BK which is counteracted by the pull on the tie in the direction BC. How does BK compare with BH? With W? Does your spring-balance reading agree with this result?

Materials Required.—Spring balance; cord; weight; model roof truss. The model roof truss may be made after the model shown in Fig. 38. Eighteen inches is a convenient length for the long timbers. The rods may be of brass. Small brass wheels about 1½ in. in diameter may be obtained from dealers in scientific apparatus with the rods fitted to them. If the wheels are not at hand the experiment can be worked by simply placing the four ends of the timbers in four carts such as are used for the inclined plane experiment.

EXPERIMENT 43

THE PENDULUM

When a clock is running too fast, should the pendulum be shortened or lengthened?

What to do:

Select two balls of the same size, iron and wood, and suspend separately by thread from a horizontal bar. A clamp will be found very convenient for attaching the

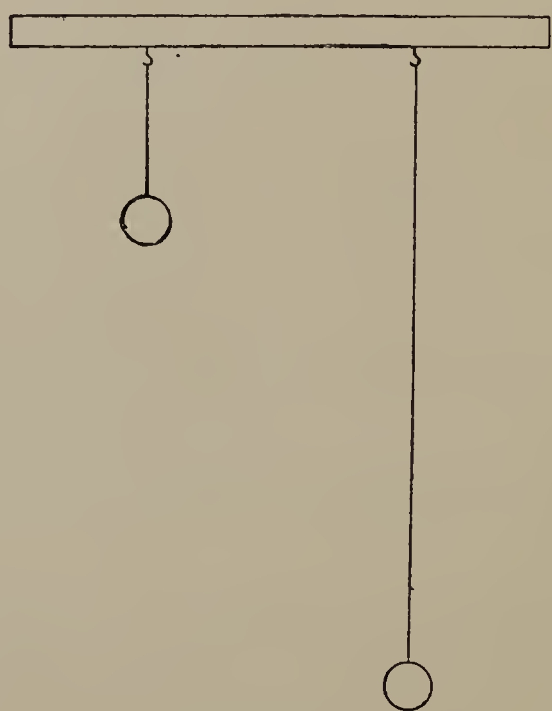


FIG. 40.

threads to the bar, especially as nice adjustments for length are needed. Set the two pendulums in vibration at the same time. A slight difference in the lengths is soon noticeable in the different rates of vibration.

Now adjust the lengths so that the distance from the lower edge of the clamps to the centers of the bobs is just

50 cm. for each pendulum. Set in vibration. Are the periods of vibration equal? If not, adjust the thread lengths till the vibrations are in the same time. The weight of one ball must be about ten times that of the other. Does varying the weight of the bob affect the period of vibration?

Now set both in vibration again, causing one to vibrate through an arc of 10°, the other through an arc of about 20°. Repeat several times, varying the arcs to small and large ones alternately. Provided the arcs are kept small (less than 20°), do you find that the period of vibration is affected by the length of the arc?

Provide some means of timing (metronome, or clock ringing minutes automatically). Adjust the lengths to 100 cm. Pull the iron bob aside and hold till the bell indicates the beginning of a minute. Then release counting the number of vibrations per minute. Repeat with the wooden bob. Take other lengths and repeat, recording results as follows:

Lengths	Number vibrations per minute	Period	Square of period
100			
50			
36			
25			

From an inspection of your results, state how the length affects the period. If a pendulum beating seconds is required to beat half seconds, what must the length be? Which length is more convenient for household clocks?

EXPERIMENT 44

WATER MOTOR POWER TEST

Where are water motors used and why?

What to do:

(*a*) Secure a water motor and attach it to the water supply as is shown in the sketch, having a pressure gauge inserted between the supply line and the motor. Arrange the motor so that the water which flows through it can be collected and weighed. (If a water meter is available insert it in the supply line and the weighing will not be necessary.)

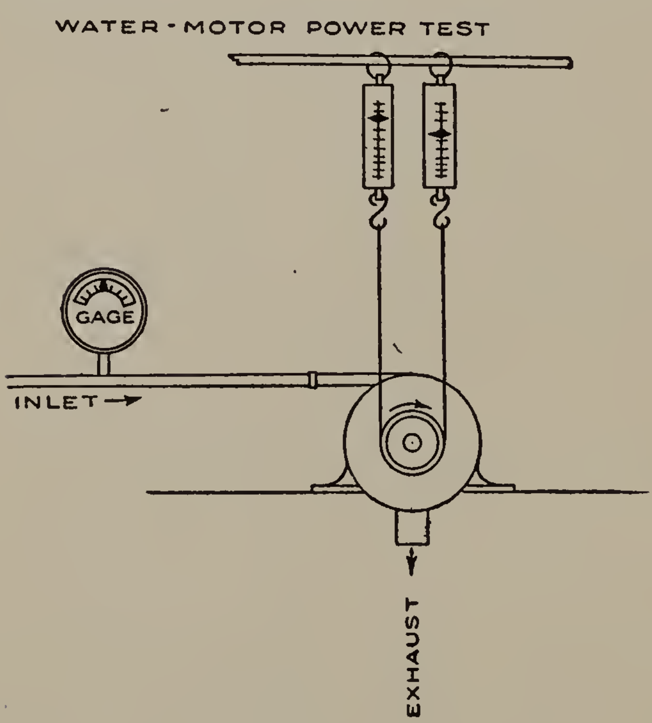


FIG. 41.

(*b*) Connect a *strap brake* as indicated, using two spring balances to register the pull. Measure the diameter of the pulley in inches. From this value find its circumference and change the reading to feet.

(*c*) Start the motor and raise the balances until they indicate some readable pull. Make note of their respective values. While they are so adjusted, find by means of a speed counter the number of revolutions the pulley is making per minute.

(*d*) While the motor is thus running read the pressure gauge and also find out how much water is passing through the motor in pounds per minute. This can be done by collecting the water in a suitable vessel and weighing or by taking note of the water meter.

$$\text{Hp. (input)} = \frac{\text{Pressure} \times \text{Volume in cubic inches per minute}}{12 \times 33{,}000}$$

$$\text{Hp. (output)} = \frac{\pi \times D \times \text{pull} \times \text{r.p.m.}}{33{,}000},$$

in which πD is the circumference of the pulley in feet, the pull being the difference of the balance readings in pounds, and r.p.m. being the speed of the motor in revolutions per minute. The value 33,000 is the foot-pound equivalent of 1 hp.

(*e*) Repeat the experiment using different pressures and different loads, and record your results in the following form:

	Test 1	Test 2	Test 3
Diameter of pulley..................			
Speed in r.p.m......................			
Balance reading *A*..................			
Balance reading *B*..................			
Net pull (*A–B*).....................			
Horsepower output................			
Gauge pressure.....................			
Pressure per square foot............			
Weight of water per minute.........			
Volume of water per minute........			
Horsepower input..................			
Efficiency (output ÷ input).........			

Materials Required.—Water motor; gauge; strap; balances; speed counter; calipers; water meter or vessel to collect water; trip scale; source of water supply.

EXPERIMENT 45

EFFECT OF HEAT ON GASES, LIQUIDS, AND SOLIDS

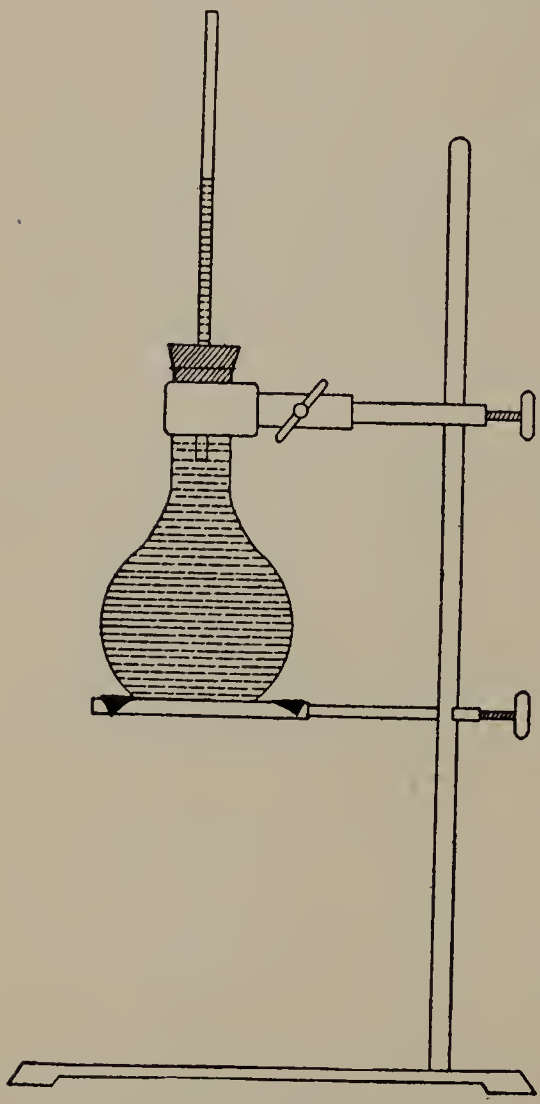


Fig. 42.

When heat is applied to a bottle of water, is there any effect on the volume of the liquid? On the capacity of the bottle?

What to do:

(*a*) Provide a Florence flask fitted with a one-hole rubber stopper through which runs a glass tube of 25 cm. length and 1 to 3 mm. bore. Press the stopper firmly into the neck of the flask, and suspend tube downward by a ring stand.

(*b*) Now place a cup of water below the tube, so that the lower end of the tube is in the water. Gently heat the air in the flask by applying the hands to the surface. Since, at the beginning, the air in the flask and tube is of definite volume, any change in that volume can be detected by the escape of air bubbles from the bottom of the tube (in case of increase), or by the rise of water in the tube (in case of shrinkage). As you continue warming the tube, is there any change in volume? Proof? State your conclusion as to effect of heat on air.

(*c*) As the air in flask cools off after the removal of your hands, do you notice any change in volume? If in doubt, apply a little snow or cold water to the surface of the flask. What is the effect on volume of lowering the temperature of the air?

(*d*) Now remove the stopper from the flask, fill the flask with water to the top of neck, stopper tightly in such a way that the water in the tube stands about midway to the top. Put a marker of some kind on tube to mark the level of the water (a string tied about is excellent). Placing the flask tube upward on the ring stand, gently heat with a Bunsen flame (see Fig. 42). Of course the heat takes effect on the glass before it does on the water which the glass contains. Is there any evidence that the heat causes the glass to expand?

(*e*) Finally, what is the convincing evidence of change in volume of the liquid under the influence of heat? When convinced as to the effect, turn out your flame, carry the flask to the sink, and apply cold water to the outer surface. Can you regain the same volume as that with which you started as shown by the marker on the stem? How could you get a smaller volume?

(*f*) State the law showing the effect of heat on volume of gases, liquids, and solids.

Materials Required.—Florence flask; one-hole rubber stopper; glass tubing length 25 cm. and bore 1 to 3 mm.; ring stand; Bunsen burner.

EXPERIMENT 46

EXPANSION OF A HEATED GAS (Household Application)

Why does a small amount of dough in a pan generally fill the pan after it has been heated? Explain.

What is the function of the crust on bread?

What causes the formation of the small holes in bread?

What to do:

(*a*) Secure a large test-tube and fill it half full of dough which contains a pinch of baking powder. Mark the level of the dough on the outside of the test-tube. Now light a Bunsen burner and adjust it so that it burns with a comparatively low flame. Hold the test-tube containing the dough about 6 in. above the flame or better so that it is heated evenly and very slowly. Turning the test-tube constantly will secure the best results. Watch the dough and note any change which might be taking place from time to time. Under no conditions allow the dough to cool after you have once started. After a few minutes you should have considerable *apparent* change in quantity. Have you really more dough now than when you started? How do you account for the change in volume? What caused the formation of the small bubbles throughout the mass? Is there any limit to the amount the dough might "rise"? What determines the height to which it might go?

(*b*) From the above facts state what it is that causes some dough, especially cake dough, to "fall" if it is removed from the oven too soon. How long should any dough be

allowed to remain in the oven? Why should some materials be baked quickly and others slowly?

Materials Required.—Large test-tube; Bunsen burner; and a small quantity of dough, which has in it a pinch of baking powder, and which is rather thin.

EXPERIMENT 47

FREEZING AND BOILING POINTS

Introductory.—Temperature is measured by means of a thermometer. This consists of a glass tube of uniform, capillary bore expanding at one end in a bulb, which acts as a reservoir for the fluid (generally mercury). In manufacturing, the bulb and the lower part of the bore are filled with the liquid. The liquid is then boiled, or heated to a degree well beyond the intended range of the instrument. This heating expands the mercury, expelling the air and filling the tube completely. While the mercury is boiling, the upper end is sealed by fusing, the heat being withdrawn from the bulb at the same moment. On cooling, the mercury contracts, leaving the tube above it a vacuum except for a little mercury vapor. Afterward as the temperature rises or falls, the mercury rises or falls in the tube accordingly. Our problem is to find out how the scale was made that we find attached to the instrument.

What to do:

(*a*) Into a cup of crushed ice or snow put the Centigrade thermometer submerging it till zero of the scale is just visible above the ice. Let it remain there several minutes till you are sure the mercury level in the tube has become stationary. Note the point of the scale at which the mercury level is at rest. Does it coincide with the zero of the scale? If not, then the zero of the scale is improperly placed and needs a correction, which you may

indicate as plus or minus the part of a degree which you find to be above or below the true freezing point.

(*b*) Now push the thermometer carefully through the hole of the stopper till the point of the scale marked 100 is just visible from the top. Push the stopper tightly into the boiler chimney. Boil the water vigorously for at least 5 minutes till you are sure the mercury level is stationary under the conditions you have. Note the point of the scale at which the mercury level is at rest. Does this level coincide with the point marked 100?

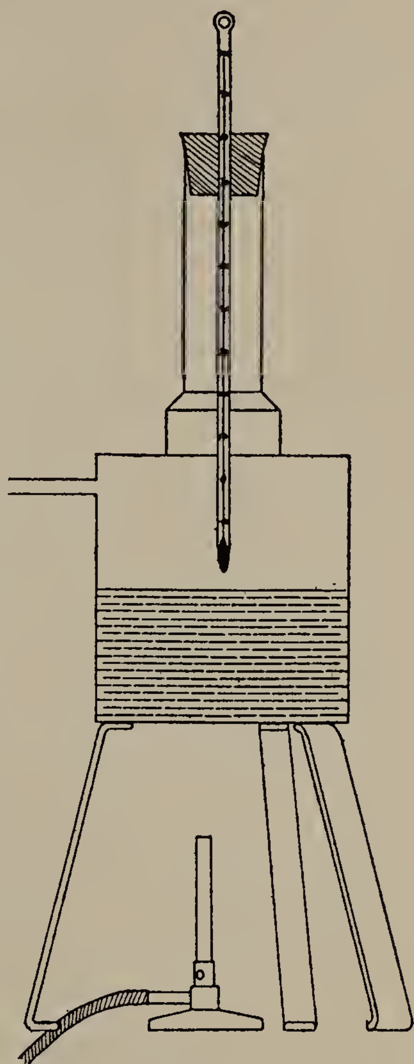


FIG. 43.

(*c*) Can the temperature be raised further after the boiling point is reached? To test: (1) turn up the flame to the utmost gas pressure; (2) replace the small burner you may have by the largest you can get; (3) if your boiler is half full or more, reduce the volume of water by one-half, and boil vigorously again. Result?

(*d*) Read and make note of the barometer reading. The true boiling point is 100° only in case the air pressure is 760 mm. and the reading is taken at sea-level (not to mention two other slight factors). Careful calculations have shown that a rise of 1 mm. above 760 mm. makes a rise of 0.037° above 100°, or a fall of 1 mm. below that makes a fall of the boiling point of 0.037°. If, therefore, the barometer reading is 740 mm., the true boiling point is 100 − (760 − 740) times 0.037°, or 99.26°.

(*e*) Record results in following form:

Thermometer Number..........

Date...................... Hour.........

Freezing Point

As observed	....
Difference	....
True freezing point	....

Boiling Point

As observed	....
True boiling point	....
Difference (error of instrument)	....

Materials Required.—Centigrade thermometer (scale −10 to 110); boiler; one-hole rubber stopper; ice or snow.

EXPERIMENT 48

HEAT CONDUCTIVITY OF WATER AND AIR

Are water and air good conductors of heat?

What to do:

(*a*) Obtain a large test-tube. Fill it with water and place in it a small piece of ice. In order to keep the ice at the bottom of the tube place a weight of some sort upon it. Now heat an iron rod (a large nail will do) red hot by means of a Bunsen burner. Hold the test-tube in the left hand near the lower end. Insert about 2 in. of the nail or rod into the test-tube of water. What is the effect? Did you note any radical change in the temperature of the lower end of the tube? What was the temperature of the water in the upper portion of the tube? Explain the results. From your observations what would you say regarding the heat conductivity of water?

(*b*) Now secure a double-walled calorimeter. Two metal calorimeters separated by a fiber ring will do. Remove the inner cup. Holding it in your hand fill it with *hot* water. Explain the result. Place the cup inside the larger one keeping the two separated by means of the fiber ring. Now take hold of the outer cup. Has this cup become heated to any great degree? Why?

(*c*) Repeat the last paragraph using in place of the hot water some *ice-cold* water.

Questions.—Why is it that you can pick up a beaker of boiling water if you use a cloth to protect your hand?

Why do you wear woolen garments in the winter time?

Why is it possible to build a bonfire on the ice and not have it burn through?

Materials Required.—Hot and cold water; large test-tube; small piece of ice; iron rod or nail; double-walled calorimeter.

EXPERIMENT 49

HEAT CONDUCTIVITY OF SOLIDS

Why are ordinary cooking utensils generally made of rather thin metals? Why not thick?

What to do:

(*a*) Obtain a glass beaker and a metal beaker of the same shape and size. They should have a capacity of about 200 c.c. Fill each about three-quarters full of water. Note its temperature. Now place the glass beaker on a ring stand having under the beaker a piece of wire gauze. Adjust a Bunsen burner so as to give a medium-sized flame and place it beneath the beaker of water. While thus heating stir the water with the thermometer and note the rise in temperature of the water during a period of 3 minutes.

(*b*) Allowing the burner to remain as it is, replace the glass beaker by the metal one and in the same manner as before note the rise of temperature of the water in it. In which case did you obtain the higher temperature?

(*c*) Now place a sheet of asbestos upon the wire gauze and repeat the experiment. What has been the result?

(*d*) Did you find that you obtained the same relative difference of temperature between the two beakers as found with and without the asbestos sheet? If any difference how do you account for it?

(*e*) Now place a sheet of iron upon the ring stand and repeat, being sure that the iron is cold before placing the second beaker upon it.

(*f*) Make a list of common good and poor conductors of heat (see Appendix, Table 7).

(*g*) (Optional.) Plates of brass, copper, tin, or other metals might also be used in place of the sheet iron.

Materials Required.—Two beakers; one metal and one glass of the same capacity; thermometer; sheet of asbestos, iron or other metal; Bunsen burner; ring stand.

EXPERIMENT 50

CONVECTION IN AIR

Why does closing the "damper" of an ordinary kitchen stove check the fire?

Why does the opening of the door of the ash pit in the ordinary furnace cause the fire to burn more vigorously?

What to do:

(*a*) Set a short candle on a piece of blotting paper. Light it and then place over it an inverted tumbler. Note carefully what happens and record your results.

(*b*) Now place over the candle a glass cylinder and note the result. An ordinary lamp chimney will do.

(*c*) Now lift the cylinder slightly. What has been the effect?

(*d*) By means of touch paper investigate the movement of the air surrounding the apparatus as set up in (*c*).

(*e*) By the same method investigate an ordinary Bunsen burner.

(*f*) Is the ventilation of your laboratory provided for by a forced draft or by ordinary convection currents? Make a diagram of the laboratory and by means of arrows indicate the condition of the air currents in it.

Questions.—What causes the "draft" in a chimney?

What would happen in a heated room if the window were lowered from the top? Raised at the bottom? Open at both top and bottom?

How do you account for land and sea winds?

Materials Required.—Piece of candle; lamp chimney or cylinders; glass tumbler; touch paper, made by soaking any porous paper in a solution of potassium nitrate.

EXPERIMENT 51

CONVECTION IN WATER

What evidence have you that there are convection currents in heated liquids?

What to do:

(*a*) Secure a glass flask. Fill it three-quarters full of water and place it over a Bunsen burner being sure to have beneath it a piece of wire gauze. Now drop into the flask a small crystal of potassium permanganate or copper sulphate. By means of a glass rod put the crystal in the center. Now heat the flask by means of the burner being sure to place the flame beneath the crystal. Record what you have observed and make a sketch to illustrate.

Questions.—In what direction does the hottest portion of a liquid move?

What name may be given this transference of heated liquid?

Where is this process used to great advantage in the ordinary home? Give at least three good illustrations.

Materials Required.—Glass flask (large); crystal of potassium permanganate; Bunsen burner.

EXPERIMENT 52

THE HOT-WATER HEATING PLANT

What to do:

(*a*) Place in the boiler a lump of copper sulphate (1 or 2 c.c.). Then arrange the apparatus as shown (Fig. 44), taking care to see that the tubing with cylinder attached

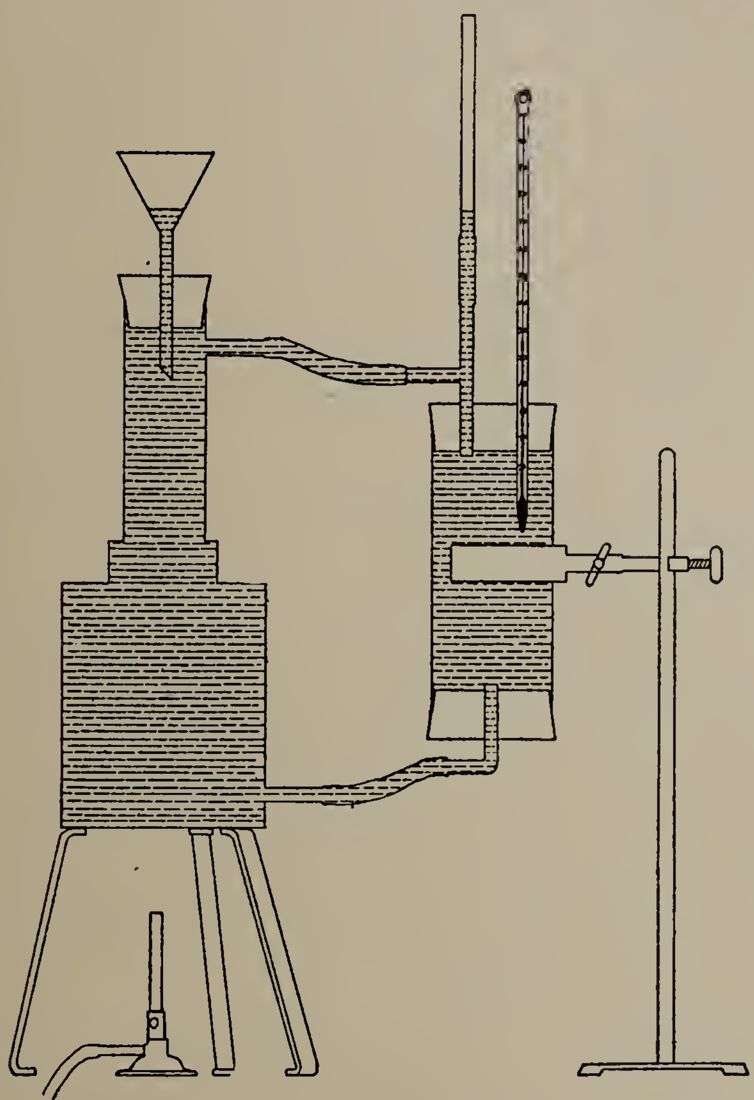


FIG. 44.

is rigidly supported. Through the funnel fill the boiler and tubing so that the water stands in funnel about halfway between outlet and top.

(*b*) Now light the burner. As the water warms, the

copper sulphate crystal will dissolve rapidly, coloring the water and making visible its movement through the gage.

(*c*) With the hand, see whether you can detect a difference in the temperature of the water in the gage, top and bottom. Repeat for the funnel. What is the difference between these readings? What has become of the heat apparently lost? If the water is flowing through the gage at the rate of 100 c.c. in a given time, and this water has cooled from 90° to 70° by the time it has reached the bottom of the gage, how many calories has the water lost and the surrounding air received? Is the water at a higher or lower level in the funnel after being heated than before?

(*d*) Besides serving as a convenient means of filling the boiler, what other purpose does the funnel serve? In general, what is the effect of heat on the volume of liquids? In hot-water plants, above the highest radiator, usually in the attic, is an "expansion tank;" can you now explain the usefulness of this tank?

(*e*) *Problem.*—If in a certain hot-water heating plant 1,000 liters of water cool from 90° to 50° per hour, how many calories does the surrounding air receive? At the rate of $4 per ton, what would be the cost of developing this amount of heat from soft coal, if we assume that the furnace is 50 per cent. efficient, and that each pound develops 3,750,000 calories?

(*f*) *Problem.*—To develop the same amount of heat from gas burning, what would be the cost at $1 per 1,000 ft. if we assume that there are available from 1 cu. ft. 150,000 calories, and that the furnace is 50 per cent. efficient?

Materials Required.—Boiler; cylindrical glass tubing; rubber tubing; glass tubing 5/16-in. (preferred); ring stand.

THE DEW-POINT

Introductory.—All free air, even the air over deserts, contains water vapor. The problem of rainfall is the problem of having a temperature low enough to make the water vapor present in the air condense. If the amount of water vapor present in a cubic meter of air at 20°C. is 5 grams (17.4 being necessary for saturation at that temperature) condensation can occur only if the temperature falls to about 1°C. (see Table 25). The temperature at which the water vapor present in the air begins to condense is known as the dew-point.

What to do:

(*a*) Provide some ice for one beaker and some tepid water for the other beaker. Rub one side of calorimeter with cloth till bright. Fill your calorimeter about one-half full of cold water. Take its temperature. Now using your thermometer as a stirring rod, slowly add bits of ice or snow, noting the temperature frequently. The instant you notice a film of mist collecting on the side of the vessel, take the thermometer reading carefully, and immediately remove from the water the unmelted snow or ice.

NOTE—It may be necessary to add a little salt.

(*b*) Now add slowly a little lukewarm water to the calorimeter till the mist begins to disappear. Note carefully the temperature at this point.

(*c*) The reading of the thermometer (¶*a*) as your mixture was cooling was too low, because we are not able to

detect the condensation the instant it appears. Likewise, the temperature you noted in the second instance (¶*b*) was too high, as what you want is the temperature at which the mist begins to disappear—not becomes visible. If you, therefore, take the average of these readings, you have the true dew-point.

(*d*) Suppose you find the dew-point to be 5°C. The water vapor of full saturation at that temperature is 4.9 grams per cubic meter (see Table 25). This amount then is the amount actually present. Suppose the room temperature is 20°C. The amount necessary to saturate at that temperature is 17.4 grams per cubic meter. The relative humidity, then, is the ratio of 4.9 to 17.4 or ......?

(*e*) Record results in following form:

	Test 1	Test 2
Temperature at which mist forms......................		
Temperature at which the mist disappears..............		
True dew-point.......................................		
Weight of water vapor present at this temperature.......		
Weight of water vapor present at temperature of room....		
Increase necessary to saturate..........................		
Relative humidity.......................................		

Materials Required.—Calorimeter; two beakers; ice; salt; thermometer.

EXPERIMENT 54

HUMIDITY

The air of the room to be healthful should have a relative humidity of about 50 per cent. Air that is too dry, "thirsty air," rapidly absorbs moisture from the skin, nose, and throat, preparing the way for the attack of disease germs. It is important to know how to test the humidity of the air and find out if it is healthful.

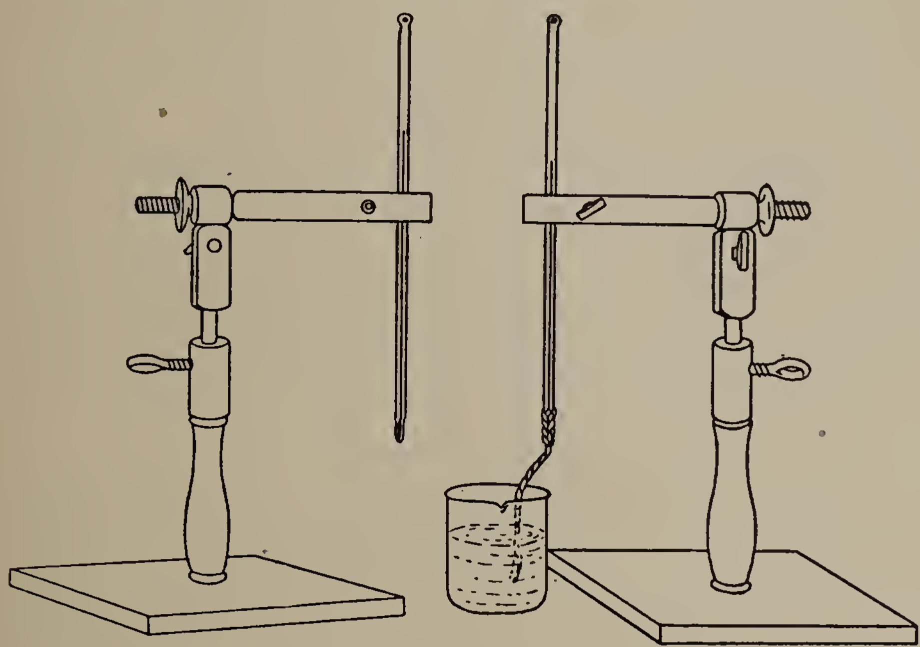


FIG. 45.

What to do:

(*a*) Place two thermometers in wooden supports as in Fig. 45. Fit a wick over the bulb of one thermometer and let the lower end of the wick dip into a beaker of water.

(*b*) When the temperatures have become stationary take the reading of each thermometer, in degrees Fahrenheit. The wet-bulb thermometer has a lower reading than the dry-bulb thermometer because water is evaporating from the bulb surface. The drier the air the more rapidly the water evaporates and, therefore, the lower the temperature of the wet bulb.

(*c*) From the following table find the relative humidity

of the air in the room. Dry-bulb readings are given in the left-hand column, difference of readings in the top horizontal line. To use the table find first the column at the top of which is the difference between the readings of the two thermometers. In this column find the number which is in the same horizontal line with the dry-bulb reading. This number is the per cent. of humidity.

Example.—Suppose the dry thermometer reading is 77° and the wet thermometer reading is 57°. Then the difference between the dry and wet thermometers is 20. Under difference between dry and wet thermometers we find 20. In the column under 20 and opposite 77 in the first column we find 26. The relative humidity in this case is 26 per cent.

Materials Required.—Two thermometers, Fahrenheit; round wick to fit thermometer bulb; two wooden supports; beaker.

Humidity Table

	Difference between dry and wet thermometers																					
Degrees..........	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Reading of dry-bulb thermometer	Per cent. humidity																					
65	95	90	85	80	75	70	65	61	56	52	48	44	39	35	31	28	24	20	17	13	10	6
66	95	90	85	80	75	71	66	61	57	53	49	45	40	36	32	29	25	22	18	14	11	8
67	95	90	85	80	76	71	66	62	58	53	49	45	41	37	33	30	26	23	19	16	12	9
68	95	90	85	81	76	71	67	63	58	54	50	46	42	38	34	31	27	24	20	17	14	10
69	95	90	86	81	76	72	67	63	59	55	51	47	43	39	35	32	28	25	22	18	15	12
70	95	90	86	81	77	72	68	64	60	55	52	48	44	40	36	33	29	26	23	19	16	13
71	95	91	86	81	77	72	68	64	60	56	52	48	45	41	37	34	30	27	24	20	17	14
72	95	91	86	82	77	73	69	65	61	57	53	49	45	42	38	35	31	28	24	22	18	15
73	95	91	86	82	78	73	69	65	61	57	53	50	46	42	39	35	32	29	25	22	19	16
74	95	91	86	82	78	74	70	66	62	58	54	50	47	43	40	36	33	30	26	23	20	18
75	95	91	87	82	78	74	70	66	62	58	55	51	47	44	40	37	34	31	27	24	21	19
76	95	91	87	82	78	74	70	66	63	59	55	52	48	45	41	38	35	31	28	25	22	20
77	95	91	87	83	78	74	71	67	63	59	56	52	49	45	42	39	35	32	29	26	23	20
78	96	91	87	83	79	75	71	67	63	60	56	53	49	46	43	39	36	33	30	27	24	21
79	96	91	87	83	79	75	71	68	64	60	57	53	50	47	43	40	37	34	31	28	25	22

EXPERIMENT 55

HEAT UNITS

How can heat be measured? Is there any difference between measuring heat and measuring temperature?

What to do:

(*a*) First note the temperature of the air in the room.

Test the temperature of a calorimeter by placing a thermometer in the calorimeter with the bulb in contact with the metal. The calorimeter should have the same or nearly the same temperature as the air. If it has not, then fill the calorimeter with water having the same temperature as the air. After 2 or 3 minutes pour out this water, dry the calorimeter with a cloth or blotting paper and again take its temperature. It will probably now have the same temperature as the air. If it has not, repeat the process.

Arrange two beakers as follows: into one beaker put 100 grams of water as cold as can be obtained from the faucet. This water should have a temperature from 5° to 15° lower than that of the air. Note carefully its temperature. In beaker number *two* place 100 grams of warm water. The temperature of this water is to be as many degrees above that of the air as the temperature of the cold water is below that of the air. It may be necessary to mix hot and cold water until the right temperature is obtained. Weigh out 100 grams of this water in beaker number *two*.

(*b*) Take the temperatures of the water in beakers *one* and *two* and immediately pour the water from both into

the calorimeter. Stir and note the temperature of the mixture. The warm water was cooled how many degrees? The cold water was warmed how many degrees?

The next step is to compute the quantity of heat that has been transferred from the warm water to the cold water. Heat is measured in calories or in British thermal units. The calorie is the unit in the metric system and the British thermal unit is the unit in the English system. A calorie is the quantity of heat gained by 1 gram of water when it is warmed 1°C. It is also the quantity of heat lost by 1 gram of water when it is cooled 1°C. Since it requires 1 calorie of heat to warm 1 gram of water 1°, how many calories does it require to warm 100 grams of water 1°? How many calories to warm 100 grams of water 2°? How many to warm 100 grams of water 3°? How many to warm 100 grams of water 5°? How many calories did the cold water receive when mixed with the warm water in your experiment? How many calories did the warm water lose? How do these two quantities compare?

(*c*) Empty the calorimeter and prepare the beakers again, placing in beaker number *one* 100 grams of cold water and in beaker number *two* 50 grams of warm water twice as many degrees above the temperature of the air as that of the cold water is below the temperature of the air.

Take the temperatures carefully, pour the water from both beakers into the calorimeter, and take the temperature of the mixture. Compute the calories gained by the cold water and the calories lost by the warm water. How do these two quantities compare?

Would 50 grams of warm water lose the same amount of heat as 100 grams of warm water if the temperature fell the same number of degrees?

State a rule for measuring the quantity of heat given up or received by a given quantity of water.

When warm water is mixed with cold water, can the cold water receive more heat than the warm water gives up, if you assume that there is no other source of heat? Can the warm water give up more heat than the cold water receives, if you assume that the heat given up is not given to anything else than the water? The answers to the last questions apply to the transfer of heat between any two substances.

(*d*) Repeat paragraph (*b*) reading temperatures on the Fahrenheit scale and taking ¼ lb. each of cold and warm water. The quantity of heat lost by the warm water and that received by the cold water may then be calculated in British thermal units. A British thermal unit is the quantity of heat required to warm 1 lb. of water 1°F. or the quantity of heat given up by 1 lb. of water when it is cooled 1°F.

Problems.—If a quart of water (2 lb.) is warmed 50°F., how many British thermal units of heat does it receive?

If 2 qt. of water at 200°F. are cooled to 50°F., how many British thermal units of heat does the water lose?

Materials Required.—Two beakers; calorimeter; thermometer with Centigrade and Fahrenheit scales, or two thermometers one Centigrade and one Fahrenheit; supply of hot water.

EXPERIMENT 56

THE CALORIMETER

Introductory Note.—In the experiments which follow it will be necessary to take account of the heat absorbed or given out by the inner cup of the calorimeter. The amount of heat which the cup absorbs when it is warmed 1° or loses when it is cooled 1° is called the water equivalent of the calorimeter. For the experiments which follow the water equivalent of each calorimeter should be given to the class by the teacher. This is simply the weight of the inner cup multiplied by the specific heat of the metal of which the calorimeter is made. A table of *specific heats* is given in the appendix (see Table 29). As a rule, all the calorimeters in the laboratory are alike and have the same water equivalent. If there are two or more kinds, the water equivalent of each of the different kinds may be given to the class.

What to do:

Fill the calorimeter with water and ice. Place in a beaker 100 grams of water at a temperature 1° or 2° above that of the room. Take the temperature of the water and ice in the calorimeter. This should be zero Centigrade. This is also the temperature of the calorimeter. Why? Take the temperature of the warm water. Quickly pour the cold water out of the calorimeter and pour in the warm water. Now take the temperature of the warm water. How many degrees or what fraction of a degree has its temperature been lowered? How many calories of heat has the warm water lost? This heat was nearly all given

to the calorimeter. How many degrees was the temperature of the calorimeter raised? Assuming that all the heat given up by the water was taken up by the calorimeter, find how many calories of heat the calorimeter took up for each degree its temperature was raised. The calorimeter, then, takes up as much heat as how many grams of water? The last result is the water equivalent of the calorimeter.

Materials Required.—Trip scales; calorimeter; thermometer; ice; battery jar, or other receptacle for emptying the water from the calorimeter.

EXPERIMENT 57

SPECIFIC HEAT

Introductory Questions.—If a pound of iron and a pound of water were both heated over a fire the same number of degrees, would they take up the same amount of heat? Would a pound of aluminum or a pound of lead take up the same amout of heat as a pound of iron, if heated the same number of degrees?

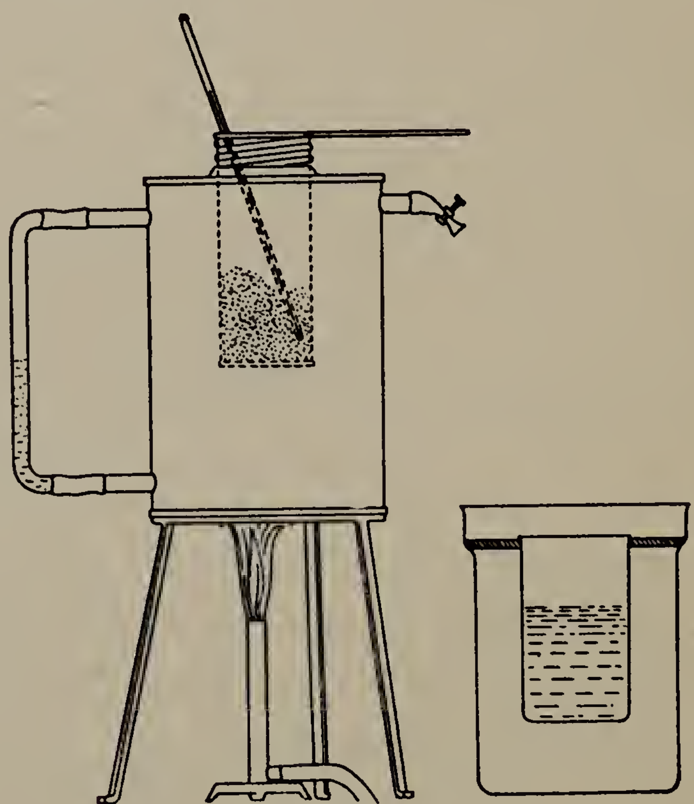


FIG. 46.

What to do:

(*a*) Place in a dipper, over a boiler, 150 grams of aluminum shot. Over a second boiler place a dipper containing 150 grams of lead in small pieces such as buck shot and over a third boiler a dipper containing 150 grams of iron

(small nails may be used). Having each boiler about half full of water, place under each a Bunsen burner. Put a thermometer into each dipper with the bulb resting on the metal. Cut out a square of asbestos paper just large enough to cover the dipper, punch a hole in the center (this can be done with a pencil) and slip the asbestos paper down over the thermometer until it rests on the top of the dipper.

While the water in the boilers is heating prepare three calorimeters as follows: weigh the inner cup of each calorimeter and put into each calorimeter 100 grams of water from the cold water faucet. Then put each inner cup into its outer cup supported by its ring.

NOTE.—If only one boiler and calorimeter can be provided for each pupil or group of pupils, the metals may be tested in succession.

(*b*) The metals are to be heated as hot as the steam will heat them. This will probably be 2° or 3° below the boiling point of water on account of the escape of heat into the air. When the temperature of the metal is near the boiling point of water and has ceased to rise, that is, when the temperature remains the same for 2 or 3 minutes, it is safe to conclude that the metals have received as much heat as they can receive from the steam.

Note the temperature of each metal carefully, then remove the thermometer. Hold the thermometer in the air for a few seconds allowing it to cool nearly to the temperature of the air, then place the thermometer in the calorimeter and note the temperature of the water. Now lift the thermometer to avoid breaking it and quickly take up the dipper containing the metal and pour the metal into the calorimeter. Stir the water in the calorimeter and note its temperature as soon as the temperature ceases to change. Make the same observations with each of the remaining two metals.

(*c*) Find how many calories of heat the water in each calorimeter received. Add to this the number of calories received by the calorimeter (see experiments 55 and 56). This sum is the number of calories given out by the metal. In other words, the heat given out by the metal is the same as the heat received by the water and calorimeter.

How many degrees was the temperature of the metal lowered? How many calories, then, would the metal have given out if its temperature had been lowered 1°? Remember that this result is the quantity of heat given out by the entire weight of metal when cooled 1°. How much heat, then, does 1 gram of the metal give out when cooled 1°? This result is the specific heat of the metal. Strictly, the specific heat of the metal is the ratio of the quantity of heat given out by the metal to the quantity of heat which an equal weight of water would give out if cooled the same number of degrees.

$$\text{Specific heat of metal} = \frac{\text{heat lost by metal}}{\begin{array}{c}\text{heat lost by equal weight of water for}\\ \text{same change of temperature}\end{array}}$$

Since 1 gram of water in cooling 1° loses 1 calorie, the divisor on the right-hand side of this equation is 1 and the number last obtained in paragraph (*c*) is divided by 1, which does not change its value. Make the same calculations for each of the metals used and compare your results with the values given in Table 29, Appendix. Answer the questions asked at the beginning of the experiment.

Materials Required.—Three thermometers; three calorimeters; three boilers with dippers (apparatus A); aluminum shot; lead bullets or buck shot; small iron nails; three Bunsen burners; asbestos paper.

EXPERIMENT 58

THE GAS METER

This apparatus (Figs. 47, 48) is used for measuring illuminating gas as taken from the service mains for household or other consumption. *P* is a rigid partition, on each side of which is a gas bag resembling a bellows. *V* is a valve, which by the mechanism of the meter is moved

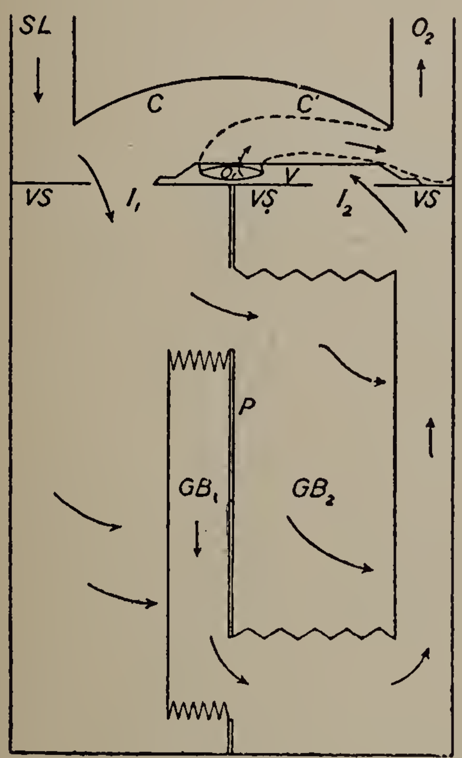


FIG. 47.

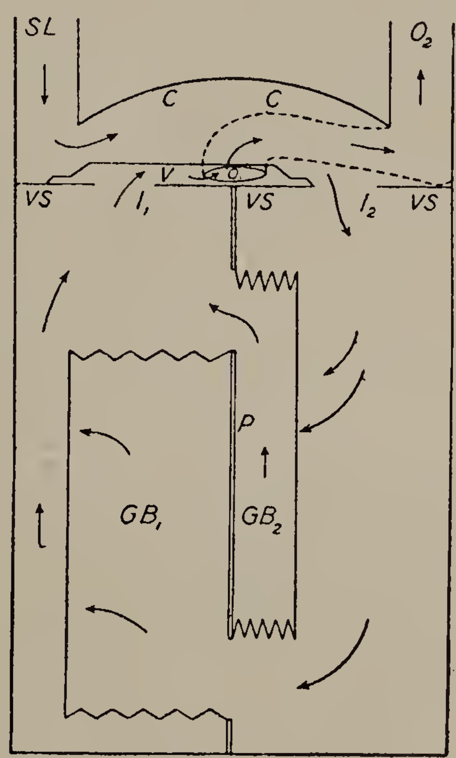


FIG. 48.

The Gas Meter.

alternately to the right and to the left on the valve-seat *VS*, thus covering or uncovering the inlets or outlets. Attached to the bellows is a lever that translates a back-and-forth movement into a rotary motion, thus driving a train of gear wheels having dial hands, D_1, D_2, D_3, D_4, D_5 (Fig. 49).

Operation.—As the gas enters the meter under pressure, if first enters the chambers *C* and *C'*. Suppose the valve

V in the position shown in Fig. 47. The gas passes through the inlet I_1 and begins expanding, causing gas bag GB_1 to collapse, and driving out its contents through the outlet O_1, thence the outlet O_2 to burners. While gas bag GB_1 is collapsing, gas bag GB_2 is filling. But by the time gas bag GB_2 is filled, the mechanism described above has moved the valve V over to the position shown in Fig. 48.

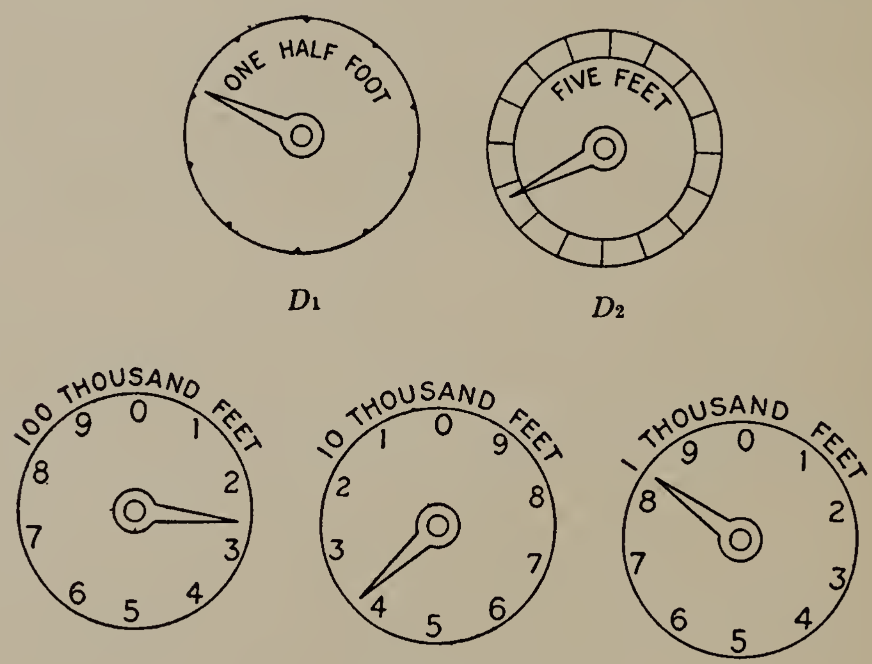


FIG. 49.

In this position, it will be noticed, the inlet I_1 is shut off from the service line SL, and opens instead into the outlet O_1 and O_2. The inlet I_2 is now open to the gas in chamber CC' Hence the gas makes the gas bag GB_2 collapse, driving out its contents through the outlet I_1 and thence through O_1 and O_2 to burners. At the same time when gas bag GB_2 is emptying, gas bag GB_1 is filling. The constant pressure of gas in the service line SL keeps one bag or the other filling, thus exerting a constant pressure in the outlet pipe O_1 and O_2

The train of gears has cogs related as 1 to 10, so that a complete revolution of dial hand D_1 turns D_2 one-tenth of a revolution, etc.

Part I

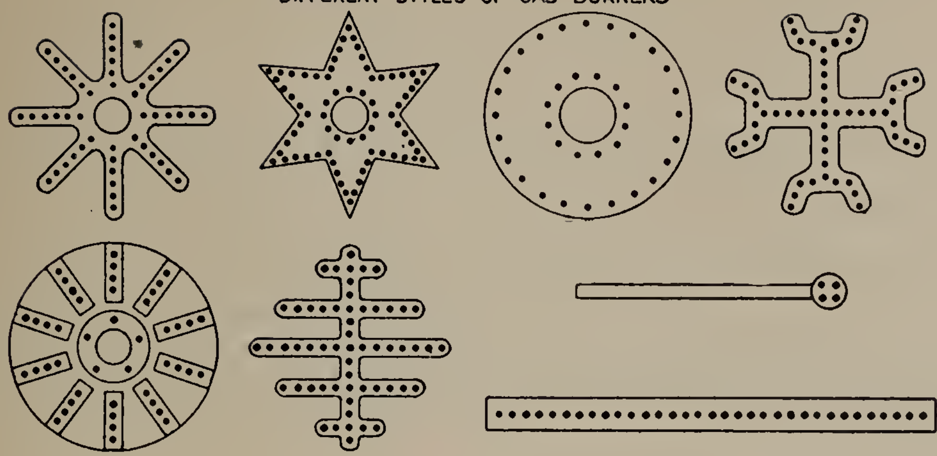


Fig. 50.

(*a*) Using three different sizes of gas burners, find in succession the time required to burn 1 cu. ft. of gas. Tabulate as below the cost per hour at 10 cts. per 100 cu. ft.

(*b*) Repeat, using two burners at once.

(*c*) Repeat, using three burners at once.

Tabulation

Burner	Time of burning	Gas consumed in same time	Cost of gas	Cost per hour at same rate
1.				
2.				
3.				
1 and 2.				
1, 2 and 3.				

Part II

Place 2 or 3 qt. of water over the largest burner, and bring it to the boiling point. Turn down the burner to the smallest flame needed to keep it boiling; then note the amount of gas burned during 15 minutes. Compute the cost at this rate per hour. Compare this cost with the

cost of same burner while under full pressure as in Part I of this experiment.

Part III

(*a*) Using the ordinary clay tip for burning gas as an illuminant, find the time required to burn 1 cu. ft. of gas.

(*b*) Compute consumption by the hour at same rate.

(*c*) At 10 cts. per 100 cu. ft., find cost by the hour.

(*d*) Repeat, using in succession the aluminum and the lava tips.

(*e*) Repeat, using a gas mantle (Welsbach).

EXPERIMENT 59

THERMAL EFFICIENCY OF BUNSEN BURNER

How much of the heat from a Bunsen burner is actually used?

What to do:

(*a*) Get the weight of the boiler in pounds (or kilograms). If the boiler is of copper, find the specific heat of copper, and determine at once the amount of heat necessary to raise that amount of copper 1° as compared with the amount necessary to raise an equal weight of water 1° (water equivalent). Place 2 or 3 lb. of water into the boiler. Take the temperature of the water.

(*b*) Get the reading of the gas meter to tenths of a foot. Arrange gas meter in series with the burner, making sure that the tubing from your gas cock leads to the INLET of the gas meter and thence by the OUTLET to your burner. Light the burner and let it burn till the gas-meter hand has reached some point on the dial convenient for reading (say 1 cu. ft). Turn off the gas and immediately take the temperature of the water. Compute the heat received by the water and the boiler. Compare this amount with the amount actually available from a cubic foot of gas (600 B.t.u.), and state the ratio of the output to the input (efficiency). Calculate likewise the rate of consumption per hour, and the cost per hour at 10 cts. per 100 cu. ft.

Tabulate results as follows:

Weight of water. . . . .
Weight of boiler. . . . .
Temperature of water at start. . . . .
Temperature of water at close. . . . .
Time (minutes) of heating.. . . . .
Heat received
By water.. . . . .
By boiler.. . . . .
Total.. . . . .
Gas consumed (cubic feet). . . . .
Heat available from this amount.. . . . .
Ratio of output to input. . . . .
Calculation of cost:
Time (minutes) of heating.. . . . .
Gas consumed per hour at same rate. . . . .
Cost per hour at 10 cts. per 100 cu. ft. . . . .

(*d*) What do you think becomes of the heat wasted as shown above? Would a hood placed around the flame and burner prevent the escape of some of this heat? Is the heat of the oven greater than it would be without the enclosing hood? Suggest some practicable ways of saving gas fuel.

Materials Required.—Boiler (apparatus A); thermometer; gas meter; Bunsen burner.

EXPERIMENT 60

EFFICIENCY OF VARIOUS COOKING UTENSILS

In a boiler of what material does water heat quickest?

What to do:

(*a*) Provide vessels of different materials, such as aluminum, copper, glass, iron, porcelain, and "graniteware" (base of iron covered with coating of glass baked on). Any vessel having a capacity of about 2 qt. will answer.

(*b*) Connect a Bunsen burner in series with a gas meter so that the quantity of gas consumed in a given time can be measured. Weigh each of the utensils, and record weights. Adjust the burner so that it burns normally and without a noisy gushing of the gas. Put into one of the dishes 2 lb. of water, noting and recording its temperature. Place over the burner, at the same time noting the reading of the gas meter, as well as the time at which your measurement of gas consumption begins.

(*c*) Read the thermometer frequently as the temperature of the water rises, being careful to put out the flame before the water starts to boil. Note and record the final temperature, the gas-meter reading, and the time at which gas consumption stops.

(*d*) Repeat for each of the other cases, being sure that you start and stop operations with the same temperature. Record and compute results as shown in the following table:

Kind of utensil				
Weight of utensil (pounds)				
Water equivalent				
Weight of water (pounds)				
Temperature at start				
Temperature at end				
B.t.u. received				
By water				
By utensil				
Total				
Cubic feet of gas used				
B.t.u. available from gas used (600 per cubic feet)				
Efficiency				
Time of run				
Cubic feet of gas per hour at same rate				
Cost of gas for each test				

Materials Required.—Kitchen dishes of aluminum, copper, glass, iron, porcelain, graniteware; gas meter; trip scales; set weights; thermometer (Fahrenheit); timepiece.

EXPERIMENT 61

TEMPERATURE OF A HOT METAL

What is the temperature of red hot iron? How can such a temperature be measured?

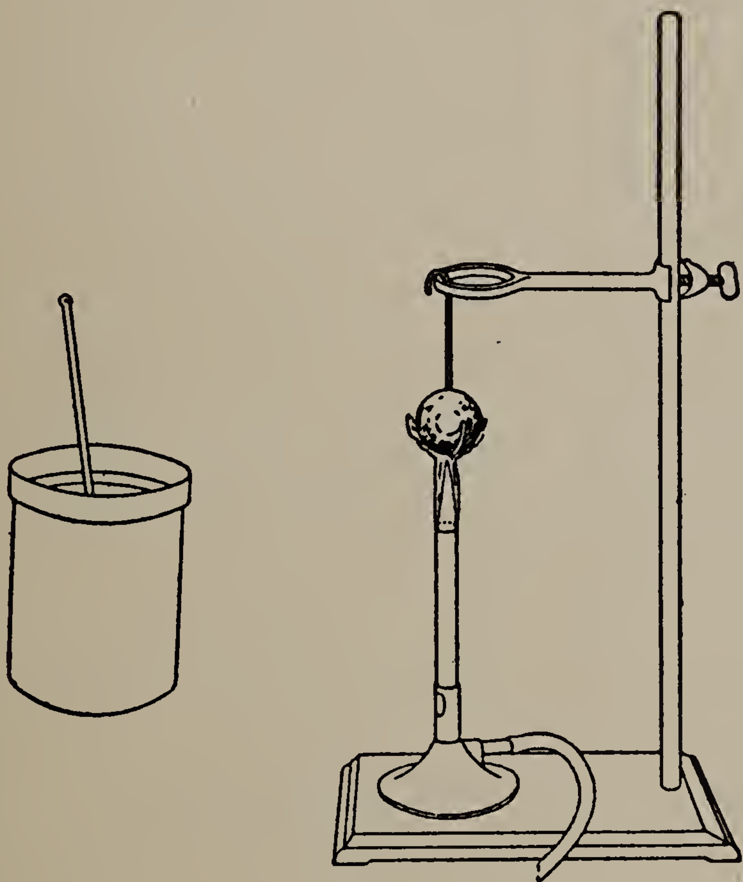


FIG. 51.

What to do:

(*a*) By means of an iron wire from an iron ring stand suspend an iron ball which has a hole drilled through it. Place a Bunsen burner so that the flame plays on the ball (see Fig. 51). While the ball is heating, weigh the inner cup of a calorimeter, put into the calorimeter about 100 grams of water, and weigh again. Have a pair of

forceps at hand with which to pick up the ball if it should drop on the table when hot.

(*b*) When the ball is red hot, take the temperature of the water, remove the flame, hold the calorimeter up close under the ball and with a pair of cutting pliers cut the wire close to the ball, allowing the ball to drop in the calorimeter. Now stir the water with a thermometer and take the thermometer reading as soon as the temperature ceases to rise. Remove the ball from the water, dry it, and weigh it with the piece of wire attached.

(*c*) Compute the number of calories of heat received by the water and the calorimeter. From the weight of the ball and the specific heat of iron compute the number of calories the ball would give up in cooling 1°. Knowing the total number of calories given up by the ball, which is the same as that received by the water and calorimeter, and the number of calories given up for each degree the ball cooled, find how many degrees the ball cooled. This temperature added to the temperature of the water after dropping the ball into it is the temperature of the ball when it was red hot.

NOTE.—This result is only approximate as there are several sources of error.

Record results in the following form:

OBSERVED RESULTS

Weight of ball	Weight of calorimeter	Weight of calorimeter and water	Weight of water	Temperature of water before dropping ball into it	Temperature of water after dropping ball into it	Rise of temperature of water

Calculated Results

Calories of heat received by water	Calories received by calorimeter	Total heat given up by ball	Heat given up for each degree of cooling (specific heat times weight of ball)	Number of degrees the ball cooled	Temperature of the ball when hot

Materials Required.—Iron ball with hole drilled through it; iron wire; iron ring stand; Bunsen burner; calorimeter; thermometer; cutting pliers.

EXPERIMENT 62

HEAT OF MELTING OF ICE

How much heat does a gram of ice take up when it melts?

Does the heat which melts the ice also raise its temperature?

What to do:

(*a*) Pour into a calorimeter 100 grams of water at a temperature of about 40°C. Provide a quantity of ice in small lumps sufficient to fill the calorimeter. Take the temperature of the water. Let the ice drip to remove the surplus water, then put the lumps of ice into the calorimeter until it is nearly full. Stir with a thermometer and note the temperature frequently. When the temperature is near zero, remove the ice that remains unmelted with a wire in the shape of a bent hair pin (see Fig. 52). By this means the ice can be removed without removing very much of the water. It may not be possible to reduce the temperature quite to zero. If it remains stationary at a degree or two above zero, note the exact temperature and remove the ice. After removing the ice, weigh the calorimeter and its contents.

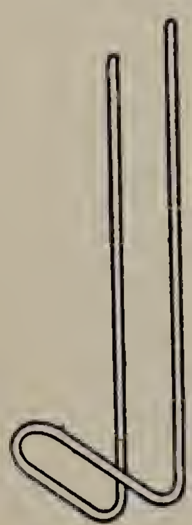


FIG. 52.

(*b*) How many grams of ice were melted? How many calories of heat did the warm water give up? Perhaps a little of this heat escaped into the air but nearly all of it was used in melting the ice. Add to this the heat given up by the calorimeter (see experiment 56). This is the

total amount of heat used in melting the ice. How many calories, then, were required to melt 1 gram of ice? This is the heat of melting of ice.

Record your results in the following form:

OBSERVED RESULTS

Weight of calorimeter	Weight of calorimeter and water before adding ice	Weight of water	Weight of calorimeter and water after adding ice	Weight of ice melted	Temperature before adding ice	Temperature after adding ice	Number of degrees water was cooled

CALCULATED RESULTS

Heat given up by water	Heat given up by calorimeter	Total heat used in melting ice	Heat required to melt 1 gram of ice

Materials Required.—Calorimeter; ice; trip scales; thermometer; wire about 8 in. long.

EXPERIMENT 63

HEAT OF SOLIDIFICATION

We have found that when a gram of ice has been raised to the melting point, 80 calories of heat are required to melt it. After the expenditure of these 80 calories, the temperature of the ice water is just 0°(C.), showing that the entire heat energy went into the work of melting. Now if we were to freeze this cubic centimeter of ice-water again, would the water in freezing give back to us the heat required to melt it?

What to do:

(*a*) Provide a freezing mixture of crushed ice or snow and salt. Fill a test-tube three-fourths full of water and push the tube into the mixture. Insert a thermometer, and take frequent readings of the temperature of the water, being careful not to stir the liquid with the thermometer, or in any way disturb it. If you proceed carefully, you will find that the temperature will drop several degrees below the freezing point without showing any signs of freezing. Note and record the lowest temperature you get before any crystallization appears.

(*b*) Now stir the water with the thermometer. Any evidence now of freezing? If so, note the temperature. Obviously, there has been a change in temperature. Since you have not furnished any heat to the water in the test-tube, from what source do you think that heat has come?

(*c*) Repeat paragraphs (*a*) and (*b*), adding, however, a small bit of ice to hasten the freezing instead of stirring the water with the thermometer. Note results.

(*d*) What conclusion do you feel justified in drawing as to the liberation of heat during the freezing process? Suggest a way by which a vegetable cellar can be kept above the danger point during severe weather.

Materials Required.—Test tube; beaker; thermometer; ice; salt.

EXPERIMENT 64

HEAT OF VAPORIZATION AND CONDENSATION

Introductory Questions.—How much heat does water take up when it changes to steam?

How much heat does steam give out when it condenses to form water?

What to do:

PART I

(*a*) Cool some water obtained from the faucet to zero Centigrade by putting ice in the water. Pour about 75 c.c. of this water into a copper beaker that will hold about 250 c.c. No ice, only the ice-cold water, should be put in the beaker.

(*b*) Place the beaker of cold water on a wire gauze over a Bunsen flame. Note the time when the flame is placed under the beaker and again when the water begins to boil. How many minutes does it take to heat the water from the freezing point to the boiling point? Do not disturb the flame or the beaker but let the water continue to boil until it has nearly all boiled away. Just before the last drops have disappeared, remove the flame and note the time. How many minutes does it take to change all the water to steam after the water begins to boil? How many times as long does it take to change all the water to steam at the boiling point as it takes to heat the water from the freezing point to the boiling point?

The water must have been receiving heat from the

flame at about the same rate all the time. About how many times as much heat, then, did the water take up in changing to steam as it took up in being heated from the freezing point to the boiling point?

The heat taken up by the water in changing to steam is called the **heat of vaporization** or the **latent heat of steam.**

PART II

The heat given out by the steam in condensing is now to be measured more carefully then the heat of vaporization was measured in Part I.

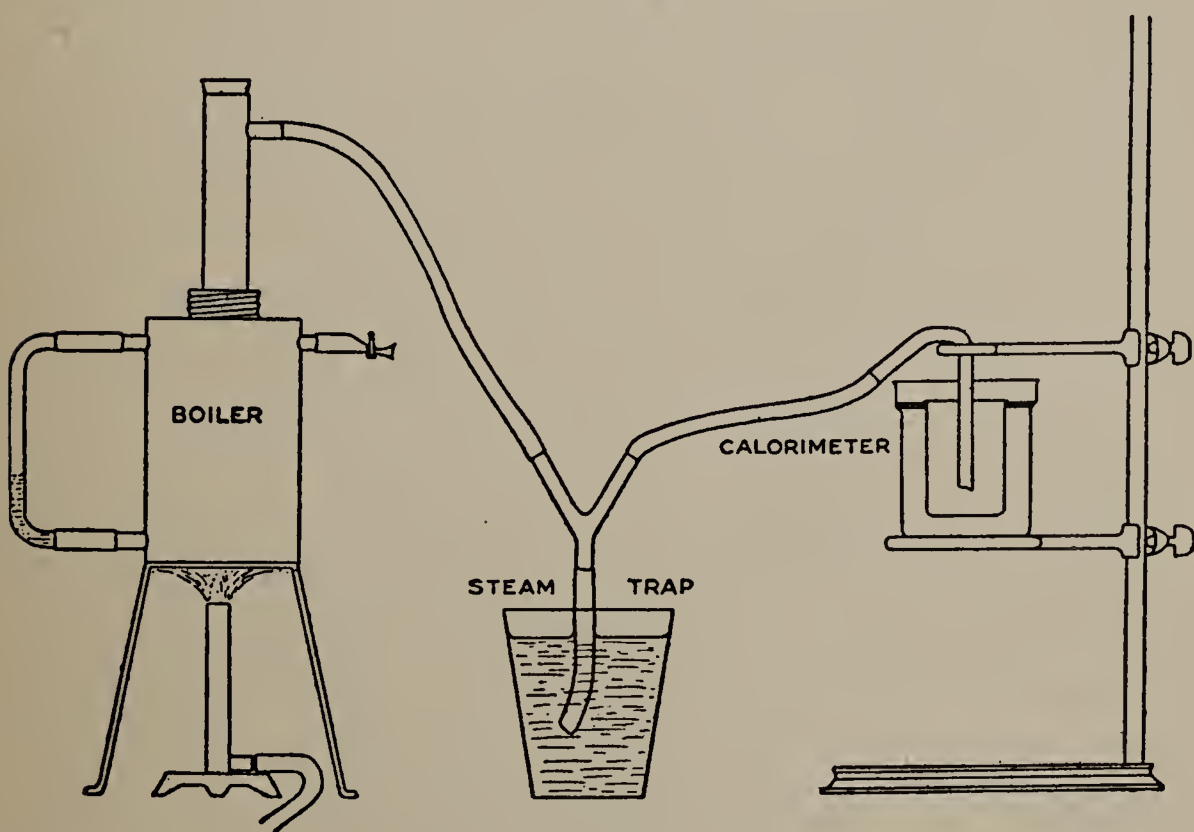


FIG. 53.

(*c*) Fill a copper boiler (Fig. 53) about half full of water. By means of a rubber tube connect a steam trap to the boiler (see Fig. 53 or Fig. 54). All other outlets for the steam should be tightly closed. Weigh the inner cup of a calorimeter and pour into this cup 100 grams of water, as

cold as can be obtained from the faucet. Light a Bunsen burner under the boiler.

Put the inner cup into the outer part of the calorimeter. Cover this cup with a piece of asbestos paper having holes for the thermometer and the glass tube. As soon as steam is flowing through the glass tube leading from the steam trap, take the temperature of the water in the calorimeter. Steam will now condense and warm the water. If the steam begins to throw the water out of the calorimeter, turn the flame lower. There should be a steady flow of steam through the water but not forcible enough to throw the water out.

(*d*) Let the steam flow until the temperature of the water in the calorimeter is the same as or very near that of the boiling water. If the temperature remains stationary for 2 or 3 minutes at a point 1° or 2° below the boiling point it is safe to conclude that this is the highest temperature which it is possible to reach with the apparatus you are using. Remove the glass tube from the water and weigh the inner cup of the calorimeter with the water it now contains. How many grams have been added to the weight of the water? This is the number of grams of steam condensed. How many calories of heat did the cold water receive? Add to this the number of calories received by the calorimeter. The sum is the amount of heat given up by the steam in condensing. How many calories of heat, then, did 1 gram of steam give up in condensing? This is the **heat of condensation** of steam and is the same as the heat of vaporization of water.

Record your results in the following form:

OBSERVED RESULTS

Weight of calorimeter	Weight of water and calorimeter before adding steam	Weight of water	Weight of water and calorimeter after adding steam	Weight of steam condensed	Temperature of water before steam flows into it	Temperature of water after steam flows into it	Rise of temperature of water

CALCULATED RESULTS

Calories of heat received by the water	Calories of heat received by the calorimeter	Total heat received by water and calorimeter	Number of calories given up by 1 gram of steam in condensing

Materials Required.—Metal beaker; calorimeter; retort stand; wire gauze; boiler (apparatus A); thermometer; asbestos paper; trip scales; Bunsen burner; steam trap.

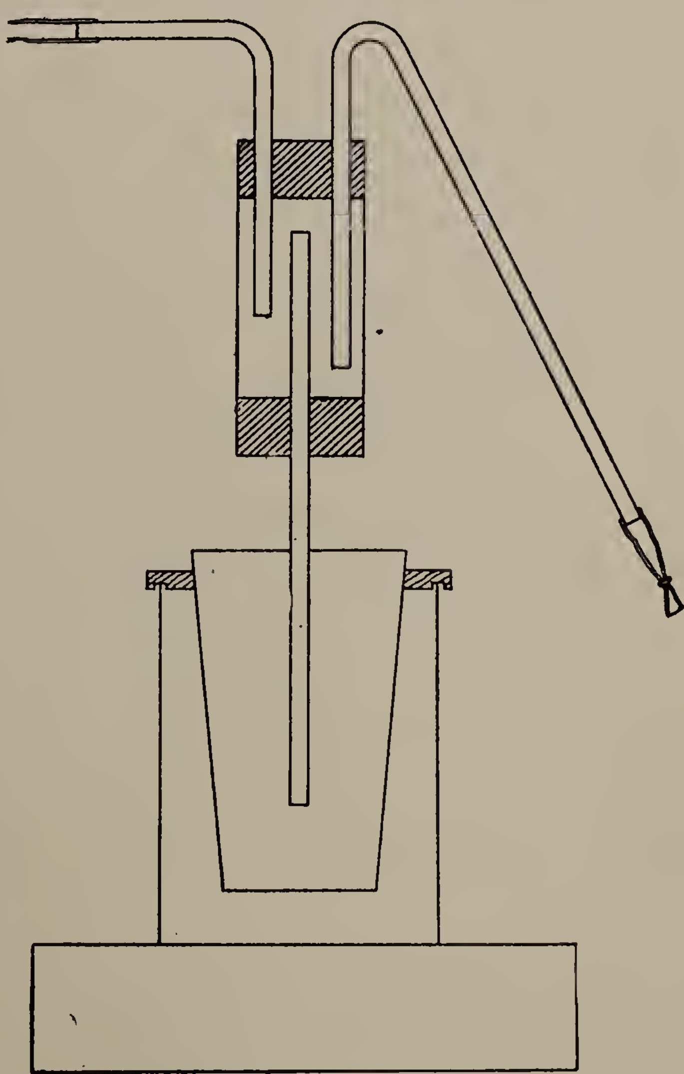


FIG. 54.—A steam trap.

STEAM TRAP

An effective steam trap is shown in Fig. 53. The depth to which the lower end of the Y-tube is immersed in water must be greater than the depth of water in the calorimeter. Steam will then flow into the

calorimeter and any water that may be formed by condensation of steam in the tube will flow back through the Y-tube into the jar of water.

Another steam trap is shown in Fig. 54. It is made of an Argand lamp chimney, two rubber stoppers, and glass tubes as shown. This trap may be substituted for the Y-tube steam trap.

EXPERIMENT 65

DISTILLATION

Of what commercial value is distillation?

What to do:

(*a*) The still generally consists of three distinct parts: (1) a chamber in which the material to be vaporized is placed; (2) a chamber in which the vaporized material is again condensed; (3) a chamber in which the condensed materials are collected. Identify these three parts in the apparatus furnished you.

(*b*) Pour some dirty water into the evaporating chamber and allow it to come up to the boiling point. Keep the cooling chamber cold by packing it with ice or by circulating cold water through it. Why must this part of the apparatus be cold? Why does the water not start to issue from the collecting spout the minute the still is started?

(*c*) Collect a little of the distilled material. Examine it very carefully. How does this differ from the material put into the still? What has become of the "dirt" or the impurities? Where can they be found?

(*d*) Name several places where the distilling process can be used to great advantage.

(*e*) Name several places where only distilled water can be used and tell why.

Materials Required.—Any common type of still; a source of heat; means of cooling still; some impure water; and a jar to collect the products in.

A Simple Still

A simple form of still may be made as shown in the sketch. Secure a flask fitted with a one-holed stopper. Bend a rather long piece of glass tubing as indicated. Fill the flask half full of water and then support on a ring stand over a Bunsen burner being sure to have a piece of wire gauze under the flask. Slip a rubber washer over the

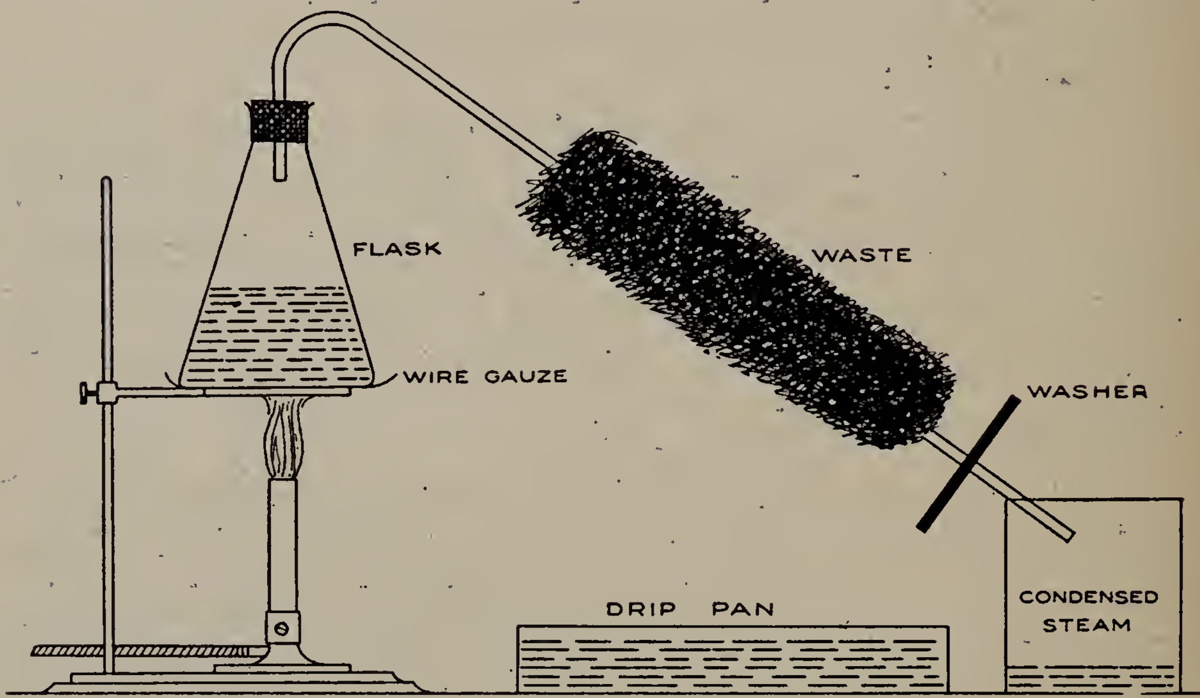


Fig. 55.

tube until it is about 6 in. from the free end. Allow this end of the tube to rest over a tumbler. Now tie some waste about the tube just above the washer. Place a *drip pan* filled with cold water directly under the waste. Light the Bunsen burner and bring the water in the flask to a boil. Do not let the water boil too vigorously but gently. While steam is slowly escaping from the tube cool it by keeping the waste wet with cold water from the drip pan. As the steam then comes from the flask it will pass through the cold portion of the tube. Some of the steam will condense and collect in the tumbler.

EXPERIMENT 66

EFFECT OF PRESSURE ON THE BOILING POINT

How can water be made hotter than water that is boiling in a teakettle? Does water ever boil at a temperature lower than 212°F.?

What to do:

(*a*) Set up the boiler as shown in Fig. 56. The pressure gauge is about half full of mercury. Put a glass tray on the table under the gauge to catch the mercury if it should be forced out by the steam. Have the pinch-cock, *A*, open. Note that the mercury stands at the same level on the two sides of the pressure gauge.

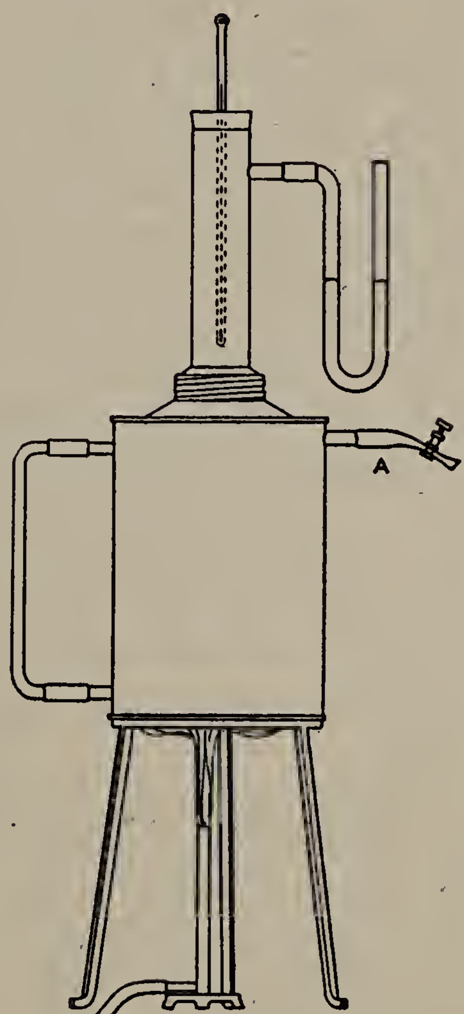


FIG. 56.

(*b*) Having the pinch-cock at *A* open note the temperature when the water is boiling vigorously and steam issuing from the tube at *A*. Slowly close the pinch-cock and watch the thermometer closely. The temperature will probably rise 1° or 2°.

CAUTION.—It is not safe to close the pinch-cock completely unless the boiler is so imperfect that steam can escape at some other point.

The mercury in the gauge will be forced down by the pressure of the steam on the side next to the boiler. Stop

turning the screw of the pinch-cock while the mercury is still safely below the outlet of the pressure gauge. Take the temperature of the steam, and measure in inches the difference of level of the mercury. This difference of level is a measure of the increase of pressure. Find from your results how great an increase of pressure is necessary to raise the boiling point 1°F.

(*c*) Fill a test-tube about half full of water and, using a wire test-tube holder, hold it over a Bunsen flame. When the water is boiling, remove the tube from the flame and quickly insert a rubber stopper. Be sure to remove the tube from the flame BEFORE inserting the stopper. The steam is now prevented from escaping and the water soon stops boiling. Its temperature is a little below the boiling point. Hold the tube over a glass tray and pour over it some cold water. If instructions have been carefully followed the water will boil again. You have apparently made water boil by pouring cold water over it. Let us see why this happened. What happened to the steam that was enclosed in the tube when you poured the cold water over the tube? How did this affect the pressure upon the water in the tube? Why then did the water boil?

Alternative Method.—Instead of using a mercury gauge, the outlet at *A* may be connected to a glass tube by means of a rubber tube, the glass tube dipping into a tall jar or pail of water. The jar should be tall enough to permit the tube to be immersed to a depth of at least 50 cm. The depth to which the tube is immersed is a measure of the pressure when steam is bubbling from the tube through the water. If there is water in the tube, the depth of the water in the tube must be subtracted from the depth of the water outside of the tube to find the true pressure. It is better to

take the readings of the thermometer when steam is bubbling through the water. Measure the depth of the water in centimeters and divide by 13.6 to find the equivalent pressure in terms of mercury.

Questions.—1. If the barometer rises 1 in., what change is there in the boiling point of water in an open vessel?

2. What is the boiling point of water on the top of a mountain where the height of the barometer is 18 in.? Remember that the boiling point is 100°C. (212°F.) when the barometer reading is 76 cm. (30 in.).

3. Is the temperature of the water in the boiler of a steam engine the same as that of water boiling in a tea-kettle (see appendix, Table 26)?

Materials Required.—Boiler (apparatus A) with mercury pressure gauge (the length of the pressure gauge should be about 6 in.); glass tray; pinch-cock; short piece of rubber tubing; thermometer in stopper to fit boiler; 6-in. test-tube with rubber stopper to fit; wire test-tube holder.

EXPERIMENT 67

COOLING BY EVAPORATION

In what way is cooling by evaporation made use of in the commercial world?

What to do:

(*a*) Secure an air thermometer and put the stem into a beaker of water which is at the room temperature. Warm the bulb slightly by placing your hand upon it. This will force out a small amount of air which will show itself as bubbles. Remove the hand and allow the bulb to come to room temperature. As it does so it will be noted that the water will rise slightly in the stem. Measure this rise by means of a ruler.

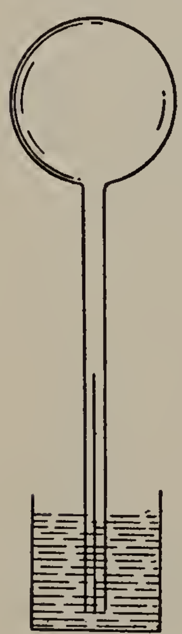


FIG. 57.

(*b*) Now place a drop or two of water on the bulb and allow it to evaporate. While this is evaporating, note very carefully the height of the liquid in the stem. Measure it now with your ruler. Has it changed? In what direction? What has been the effect on the gas in the bulb?

(*c*) Repeat paragraph (*b*) using in place of water a few drops of alcohol. Then repeat using ether. Which of these liquids has produced the greatest effect?

(*d*) Now moisten the bulb of a thermometer with water and allow the water to evaporate. While it is doing so note carefully the temperature. Repeat using alcohol and then ether. What was the effect of each? What are

your conclusions regarding the effect produced by evaporation? Where is this effect used to great advantage?

(*e*) Explain the expansion system of refrigeration.

Materials Required.—Small beaker; air thermometer; mercury thermometer; a little alcohol and ether.

EXPERIMENT 68

A FREEZING MIXTURE AND THE FREEZING OF WATER

A mixture of salt and ice is used in freezing ice cream. Why is this mixture better than ice alone?

What to do:

(*a*) Put two lumps of ice of about equal size into a glass tray and sprinkle salt over one of the lumps. Find out which piece of ice melts faster.

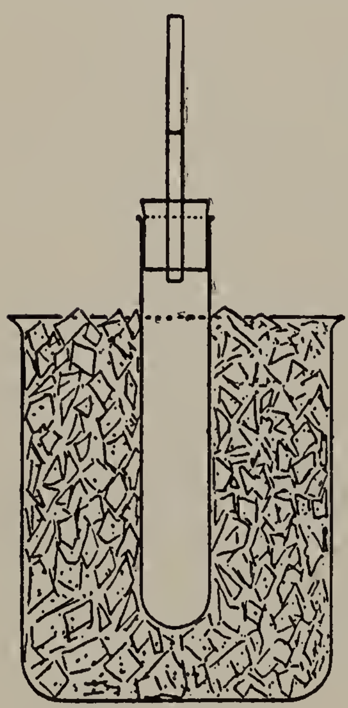


FIG. 58.

(*b*) Fill a test-tube with water and insert a one-hole rubber stopper having a glass tube about 6 in. long in the stopper. Put the test-tube into a beaker and pack closely around it a mixture of salt and small lumps of ice (see Fig. 58). Observe the water in the glass tube closely. Does water expand or contract when it freezes? Does your experiment furnish any evidence to enable you to answer this question? With the thermometer find the temperature of the mixture of salt and ice. Compare this temperature with that of freezing water.

The ice which is mixed with the salt is melting. What about its rate of melting? See paragraph (*a*).

Does ice take in or give out heat when it melts?

Why, then, does the water in the test-tube freeze?

Materials Required.—Test-tube fitted with one-hole rubber stopper and glass tube about 6 in. long; beaker; salt; ice; thermometer.

EXPERIMENT 69

RELATIVE COOLING EFFECTS OF ICE AND ICE-WATER

Why is it better to use ice than ice-water in a refrigerator?

What to do:

(*a*) Put into each of two pails or large metal cups a pound of water and place each over a Bunsen flame. Into another cup place water and lumps of ice. Stir the ice and water until the temperature of the water ceases to go down. Remember that the water is now just as cold as the ice, provided some ice remains unmelted.

(*b*) Pour the ice-water into a fourth cup holding back the ice with a wire gauze. Weigh out ½ lb. of ice-water and ½ lb. of ice. When the water is boiling in the first two cups, remove the flames. Pour the ice-water into one of the cups of boiling water and drop the ice into the other. Stir the mixture of boiling water and ice-water and take the temperature. Take the temperature of the water into which the ice was poured as soon as all the ice has melted.

Which cools the hot water more, the ice or the ice-water? Find the number of B.t.u. given up by the boiling water in each of the two cups (see experiment 55).

Record results as follows:

Weight of boiling water in each cup, 1 lb.

Weight of ice, ½ lb. Weight of ice-water, ½ lb.

	Temperature of mixture	Heat lost by hot water
Hot water and ice................		
Hot water and ice-water..........		

Explain the difference between the two quantities of heat lost. Answer the question asked at the beginning of the experiment and give a good reason.

Materials Required.—Four pails or metal cups holding not less than 1 qt.; tray to receive excess of water or ice; two ring stands; thermometer; trip scales; weights; supply of ice; wire gauze.

EXPERIMENT 70

RELATIVE HEATING EFFECTS OF STEAM AND BOILING WATER

Which gives out more heat, steam or an equal weight of boiling water?

What to do:

(*a*) Light a Bunsen burner under a boiler which is about half full of water. While the water is heating prepare two calorimeters as follows: Pour into each 100 grams of water as cold as can be obtained from the faucet. Take the temperature of the water. Place one of the calorimeters on the trip scales. Place weights on the other platform of the scales to balance the calorimeter. Now place an additional weight of 20 grams on the weight side of the scales.

(*b*) Pass steam from the boiler into the water until the scales are again balanced. Twenty grams of steam will then have been condensed. Again take the temperature of the water.

(*c*) Weigh out 20 grams of water in a beaker and bring it to the boiling point. Pour this boiling water into the cold water in the second calorimeter and take the temperature of the mixture. Which heats the cold water more, the steam or the boiling water?

(*d*) Compute the number of calories given to the cold water by the boiling water. Compute also the number of calories given to the cold water by the steam (see experiment 55).

Which gives out heat more rapidly, a steam radiator or a hot-water radiator?

Materials Required.—Boiler with tubes for passage of steam; two calorimeters; trip scales and weights; beaker; ring stand.

EXPERIMENT 71

HEAT INSULATORS

Introductory.—The purpose of this experiment is to test the heat-insulating values of various materials in common use. The wrappings needed (asbestos and wool-felt) are easily had and easily prepared because in common use for insulating steam pipes. In preparing the

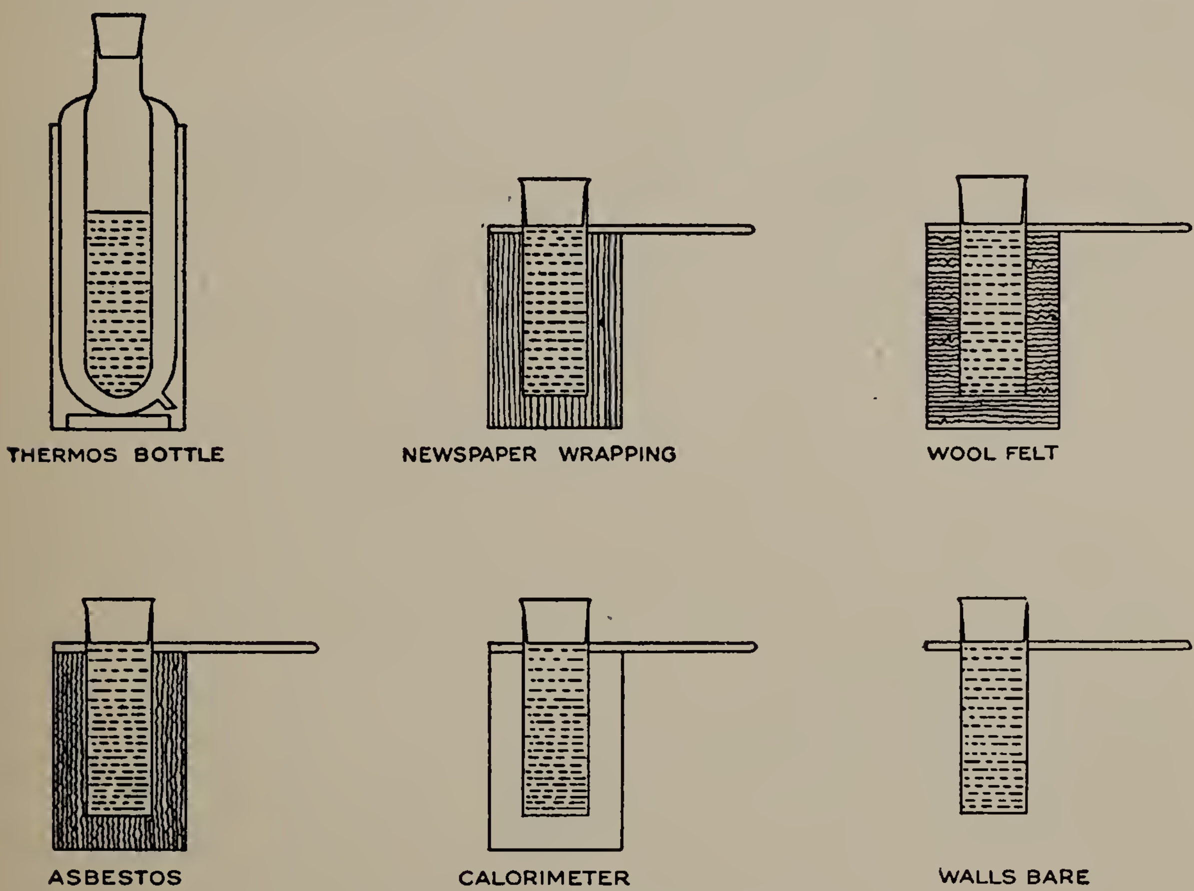


FIG. 59.—Heat insulators.

asbestos and other wrappings, cut off the tubular wrappings at least an inch longer than the cups they are to contain so as to have room for making a bottom. Then when making the asbestos container, moisten a handful

of loose asbestos, and while the dipper is in place inside the casing, stuff the moist asbestos into the tube from the bottom upward. Fit bottom in snugly around the walls. Finally, see that you have for each vessel a close-fitting cork stopper, preventing loss of heat by radiation and making access to the liquid easy for the thermometer readings.

What to do:

(*a*) Boil sufficient water to fill all the vessels at once.

(*b*) Having all the vessels standing ready in their insulators, fill them in succession with boiling water to within an inch of the top, and immediately take and record the temperature of each. Insert the cork stopper as soon as the reading is taken.

(*c*) At intervals of about 10 minutes continue taking thermometer readings for as long a time as your laboratory time permits. Tabulate as follows:

	Temperature										
Hour........................											
Insulating material..............											
Copper (single-walled)...........											
Copper (double-walled)..........											
Paper (newspaper wrapping).....											
Wool-felt (steam-pipe wrapping).											
Asbestos (steam-pipe wrapping)..											
Thermos bottle.................											
Fireless cooker.................											

NOTE.—A refrigerator of size fit for household use, though desirable in this experiment, is unsuitable because the air inside the box would absorb the heat from the container and water, neutralizing any possibility of getting usable insulating results.

(*d*) Repeat the experiment, using ice-water instead of boiling water.

(*e*) Which vessels do you find best insulated? Which poorest?

(*f*) If you were to make an ice-box or refrigerator, which insulating materials would you select, having in mind the cost and insulating value?

Materials Required.—Thermometer; boiler; several cylindrical vessels of uniform capacity, preferably the copper dippers provided with apparatus A; fireless cooker; thermos bottle; heat insulators consisting of as many of the following as can be had: asbestos, wool-felt (steam-pipe coverings having inside diameter of 2 in.), newspaper wrapping (loose), double-walled copper calorimeter, cork stoppers for dippers.

EXPERIMENT 72

THE FIRELESS COOKER

Introductory.—The connection between this experiment and that on Heat Insulators is close. There the relative values of various materials were tested out to determine which best prevent the loss of heat by radiation. The fireless cooker is merely a special adaptation of the principle there discovered, the best heat-insulating materials being chosen for use in the fireless cooker. Quite commonly the heat-insulating material is, first, wood (the outer casing), then layers of paper, cork, sawdust, and finally (next the inner walls) asbestos. A certain closeness of the particles of the packing material is very desirable—loose enough to hold "dead air," yet not so loose as to allow convection currents. For sanitary reasons, the middle of the cooker consists of a metal can, which serves the double purpose of providing the inmost wall for the insulators and of protecting those insulators against liquids that may be spilled. It may be added that the insulators good for a fireless cooker are equally good for a refrigerator, the two devices being usuable for either purpose.

In practice, there are three methods of applying the heat to the food to be cooked: (1) The food contained in a well-covered kettle is brought to a suitable temperature over a flame and then quickly transferred to the cooker, the lid over which is closed air-tight. (2) A "radiator" (soapstone) is brought to a high temperature

over a flame, and then put inside the cooker on a rack. The kettle containing the food is placed over the stone, and the box lid then closed down air-tight as in the other case. (3) By an electric heating-coil placed in the lower part, the cooker is heated to the temperature desired. Then the food is enclosed, and the current turned off.

What to do:

(*a*) If possible, examine the diagram that usually accompanies a fireless cooker, and determine the kinds of insulating materials used and their order from the outside inward. Make a drawing to illustrate the plan of insulation.

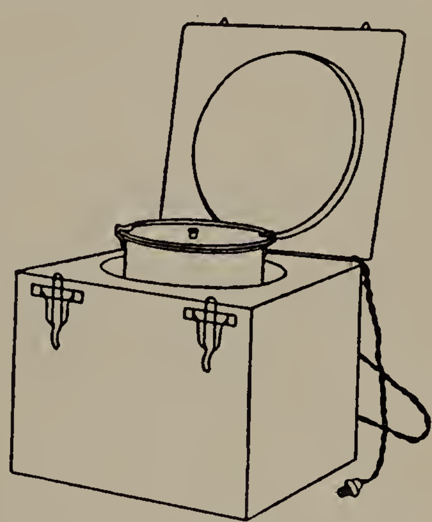


FIG. 60.—A fireless cooker.

(*b*) Place 4 lb. of water into the cooker kettle, noting the temperature, and the time. Start the burner, noting at the same time the reading of the gas meter.

(*c*) Just as the water comes to the boiling point, remove the kettle, place inside the cooker quickly, and close down the lid air-tight. Determine the gas consumption for the time of run, and compute what the consumption would have been on a 3-hour run (average time for roasting).

(*d*) At intervals of (say) 30 minutes, take temperature readings for as many hours as possible.

(*e*) Suppose that at the end of 4 hours the temperature has fallen to 150°(F.). Does food cook at that temperature? If the walls were perfect insulators against heat, what would be the temperature at any time the lid should be opened?

(*f*) If time permits, place 4 lb. of ice-water (32°F.) into the cooker, and take temperature readings for as many hours as possible. Do you find the cooker serves

equally well for a refrigerator? Does the cold water warm up at the same rate as the hot water cooled down in (*d*)?

(*g*) If 4 lb. of boiling water cool to 180°(F.) in 3 hours, find the B.t.u. lost, and the rate of loss per hour per pound. Would a 5-lb. stone or a 5-lb. roast of beef cool off at the same rate?

Materials Required.—Fireless cooker; gas meter; burner; thermometer.

EXPERIMENT 73

TEMPERATURE OF OVENS

Introductory.—One of the most important applications of temperature measurement is the testing of oven temperatures. The temperature of an oven is not as a rule uniform, that is, different parts of the oven are not at the same temperature. It is important to know how the temperature at the center of the oven differs from that at the door. Ovens are not alike but an experiment on testing oven temperatures will make baking less a matter of guess work. Since not all ovens are provided with oven thermometers, it is important to know certain methods of estimating temperatures without a thermometer and to know the temperatures that may be approximately secured by these methods.

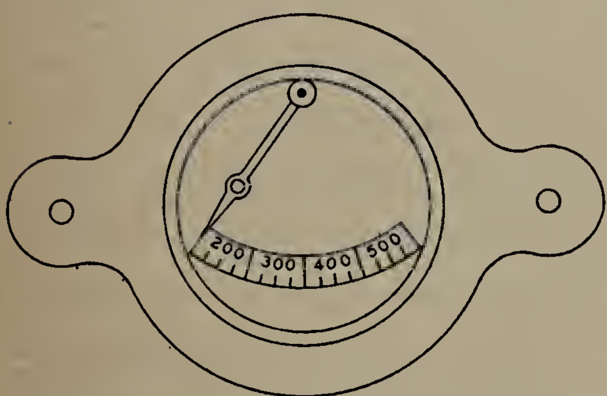


FIG. 61.—Oven thermometer.

The "working part" of an oven thermometer is a coil of metal which expands when heated as all metals do. As the coil expands it attempts to unwind and as it does so it moves a pointer to which it is attached. The pointer moves over a scale which should be marked in degrees Fahrenheit (see Fig. 61). Unfortunately some oven thermometers are not marked in degrees but have only such meaningless markings as "warm," "hot," "very hot."

What to do:

(*a*) Secure a small gas oven that has an oven thermometer in the door or in one side and a means of observing a mercury thermometer suspended near the center (see "Materials Required" below). The mercury thermometer should read as high as 500°F.

(*b*) With the thermometers in place ready for observation light a Bunsen burner or a small gas stove under the oven. Watch the oven thermometer closely and the instant the pointer begins to move read the mercury thermometer. Continue the readings, taking the readings of both thermometers each time the pointer of the oven thermometer has moved one scale division.

CAUTION.—If the mercury reaches a point within 25° of the top of the scale, turn off the gas. If this is not done the mercury may reach the top and break the glass stem of the thermometer.

What differences do you observe between the temperature at the door and at the center of the oven? Write these temperatures in parallel columns showing the temperatures that occurred at the same instant.

(*c*) Remove the flame, open the oven door and allow the oven to cool. Then place five pieces of light-brown wrapping paper or newspaper on a grate in the center of the oven close to the bulb of the mercury thermometer. Again light the gas under the oven. When the temperature has reached 250°F. open the door and quickly take out one piece of paper and close the door. Do the same thing at each of the following temperatures: 300°, 350°, 400°, 450°.

By putting your hand in the oven at these temperatures you will learn that it is possible to estimate roughly by this means alone the temperature of the oven.

Paste the five pieces of paper in your notebook and

under each the temperature at which it was taken from the oven.

"The temperature for baking small cakes, muffins, biscuits and layer cakes varies between 425°F. and 450°F; for loaf bread or cake, from 375°F. to 400°F." (Taken from "Foods and Household Management" by Helen Kinne and Anna M. Cooley.)

When we are privileged to have electric ovens with glass doors and an accurate thermometer, baking will be an easy and accurate process.

Materials Required.—Bunsen burner or small gas stove; iron support for oven if Bunsen burner is used; mercury thermometer reading to 500°F., small gas oven fitted with an oven thermometer. An oven thermometer costing $1 can be obtained from the Cooper Oven Thermometer Co., Pequabuck, Conn. By means of a metal drill an opening can be made in the side of a gas oven and the oven thermometer attached. If the oven has a glass or mica door a mercury thermometer may be supported on an iron grate with the bulb near the center of the oven and readings taken through the door. If the oven door is iron it will be necessary to drill through the top of the oven for the insertion of the mercury thermometer. The thermometer should then be inserted so that the stem from about 250° up is above the top of the oven. Asbestos paper should then be packed around the thermometer at the opening in the oven.

EXPERIMENT 74

COOKING TEMPERATURES

What to do:

(*a*) Arrange cups and materials for application of heat as follows:

(1) Boiler containing water; (2) double boiler (copper dipper of apparatus A inserted through the top), both parts containing water; (3) covered "steamer"—apparatus A with thermometer tube screwed on top; (4) beaker or test-tube containing sirup made of equal parts (by weight) of sugar and water; (5) beaker or pan of fat (lard, tallow, cottolene, or crisco); (6) fireless cooker containing pail or kettle full of boiling water; (7) oven; (8) salt brine.

(*b*) Heat each vessel (except fireless cooker) not less than 15 minutes, or long enough to satisfy yourself that you have characteristic values.

(*c*) Tabulate results as follows:

Liquids showing constant temperature after boiling point is reached..

Liquids showing constant rise of temperature during heating..

Instance of falling temperature........................

Instances of high-cooking temperatures (above boiling point of water)..

Instances of low-cooking temperatures (below the boiling point of water)....................................

Materials Required.—Boiler (apparatus A), with thermometer tube and copper dipper; several beakers or test-tubes; sirup; oven; salt brine; pan of fat; thermometer with range of 0° to 315°C. (600°F.).

EXPERIMENT 75

MEASURING THE WASTE OF ICE IN REFRIGERATORS

What to do:

(*a*) Put a block of ice into the refrigerator. Assuming the walls air-tight, let us first consider what would happen if they were perfect heat insulators. The ice absorbing heat from the enclosed air and the walls would melt till the temperature of the box fell to the melting point of ice, and then would cease melting altogether. What remained of our block of ice when the box reached this temperature (32°F.) would thus last indefinitely. Manifestly, however, there is no perfect heat insulator. Hence the ice goes on melting, and the temperature of the box always remains considerably above the melting point, the amount depending on the rate at which the ice can absorb heat through the imperfect insulating walls. A good ice-box is, therefore, seen to have two characteristics—a low temperature, and a low ice-wastage rate.

(*b*) Some time later (say 24 hours) determine the amount of ice that has melted, and the temperature of the waste water. Suppose 20 lb. of ice has melted, and the temperature of the waste water is 41°F. It required 144 B.t.u. to melt each pound of ice, and an additional 9 B.t.u. to raise this pound of ice-water to 41°, or a total of 153 B.t.u. Since 20 lb. have escaped, the total heat work done is represented by the product of 153 and 20, or 3,060 B.t.u.—almost exactly the equivalent heat due to burning 5 cu. ft. of illuminating gas.

(*c*) Of course the value of this experiment is greatly increased, if there be available several refrigerators for testing. The box found to be the best insulator can then be accepted as the standard, others being compared with it as a standard.

Record results as follows:

	Tests		
	I	II	III
No. of pounds of ice at beginning			
No. of pounds of ice melted			
Temperature of waste water			
B.t.u. needed to			
Melt ice			
Raise ice-water to temperature of waste water			
Total			
Rating of boxes as regards ice waste			

Material Required.—Refrigerator (several, if possible); block of ice; thermometer; scales.

EXPERIMENT 76

FOOTWARMERS—HOT-WATER BOTTLE AND FLAT IRON

Which is better for supplying heat for a sick person, a hot-water bottle or an iron and why?

What to do:

(*a*) Find the weight of an ordinary flatiron. Pour into a tin pail a weight of water equal to the weight of the iron. Then put the iron into the water. Have two other pails ready. Into each of these pails pour the same weight of water that you put into the first pail. Place the pail containing the water and the iron over a gas flame and let the water boil. The iron and the boiling water are now at the same temperature.

(*b*) With a hook made of strong wire lift out the iron and place it in one pail of cold water. Pour the boiling water into the other pail of cold water. Take the temperature of the water in each pail after about 1 minute. Which gives out more heat, the hot water or the iron?

(*c*) How many degrees was the hot water cooled? How many B.t.u. of heat did it give up? How many degrees was the flatiron cooled in the cold water? How many degrees was the cold water warmed? Multiply the number of degrees the cold water was warmed by the weight of cold water. This result is the number of B.t.u. given to the cold water by the iron. How many degrees was the iron cooled? Then how many B.t.u. would the iron give up if cooled 1°? This result is called the heat capacity of the iron.

To what temperature would it be necessary to heat the iron so that it would give out the same amount of heat as the hot water? Would it be comfortable at that temperature? Answer the question asked at the beginning of the experiment and give a good reason for your answer.

Materials Required.—Flat iron weighing about 3 lb.; three tin pails large enough to hold the iron; Bunsen burner; iron ring stand; thermometer; hook made of strong wire.

EXPERIMENT 77

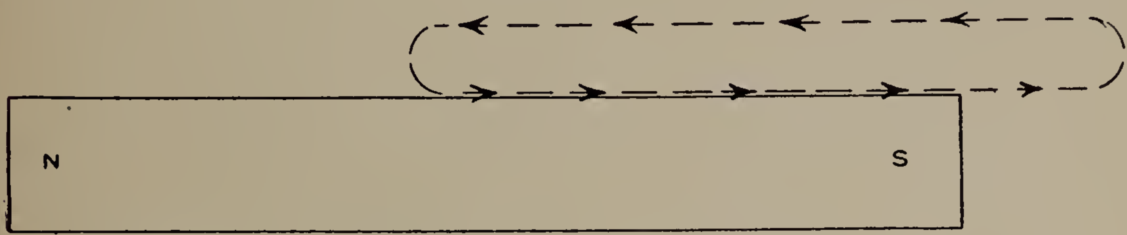
MAGNETISM

MAGNETIC SUBSTANCES

How can magnetic substances be distinguished from non-magnetic substances?

(*a*) What to do:

Obtain a small quantity of a mixture of various materials. Stir this mixture with a piece of watch spring and note the result.



METHOD OF MAGNETIZING WATCH - SPRING

FIG. 62.

(*b*) Now draw one end of the watch spring over a bar magnet, as shown in the sketch, starting at the center and drawing the spring toward either end of the magnet, removing the spring when the end is reached. Repeat this four or five times. Stir the mixture as in (*a*) and note any change in its action. Identify the materials which cling to the watch spring.

(*c*) The watch spring has, through contact with the bar magnet, become a magnet, or better has been magnetized. Any materials which are attracted by a magnet are said to be *magnetic* and all others are *non-magnetic*.

Questions.—How many magnetic materials did you find in the mixture? Name them.

Materials Required.—Magnet; watch spring; and a mixture (small pieces of paper, wood, sand, metal filings of iron, brass, zinc, copper, and lead).

NOTE.—In returning the magnets to the instructors table be sure to place them so that *unlike* ends touch each other. Do not allow the magnets to fall on the floor or the table as this will tend to demagnetize them.

EXPERIMENT 78

ATTRACTION WITHOUT CONTACT

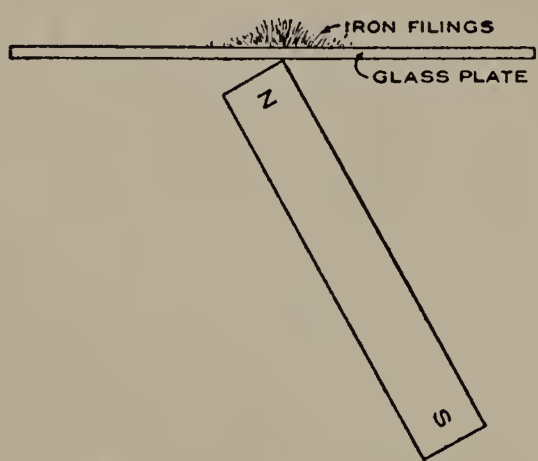
Is contact necessary for magnetic attraction?

What to do:

(*a*) Place a few iron filings upon a piece of paper. Bring a bar magnet near to them and note the result.

(*b*) Now hold the pole of a magnet directly beneath the filings on the under side of the paper and move the magnet back and forth always in contact with the paper. What are your conclusions from the above results?

(*c*) Repeat the above operation using in place of the paper some glass, brass, copper, zinc, hard rubber, wood, and iron.



MAGNETIC ATTRACTION WITHOUT CONTACT.

FIG. 63.

(*d*) Was there magnetic action with all of the above materials? If not, with which did you fail to get results? If there are any materials which seem to cut off the magnetic action they may be called *magnetic screens*. Make a list of them. Can you tell why they act in this way?

Materials Required.—Pieces of glass, brass, copper, zinc, hard rubber, wood, and iron; a bar magnet; and some iron filings.

EXPERIMENT 79

POLARITY

How can the polarity of a magnetized piece of watch spring be determined?

What to do:

(*a*) Allow a piece of unmagnetized watch spring to float on the surface of a dish of water. Note its position and then turn it so that its position is changed and allow it to come to rest. Try again but this time with a piece of spring that has been magnetized.

(*b*) Note carefully the end of the magnetized spring which pointed toward the north. Mark it so that you can later identify it. Call this end the *north-seeking* (N-S) and the other, the *south-seeking* (S-S), end.

(*c*) Now draw the magnetized piece of spring through some filings and make a sketch of the spring with the filings clinging to it. The places at which the filings have gathered in greatest numbers are called *magnetic poles.*

Questions.—Does every magnet have poles? How many? How many poles may a magnet have?

Materials Required.—Glass dish half filled with water; filings; unmagnetized watch spring; and a magnet.

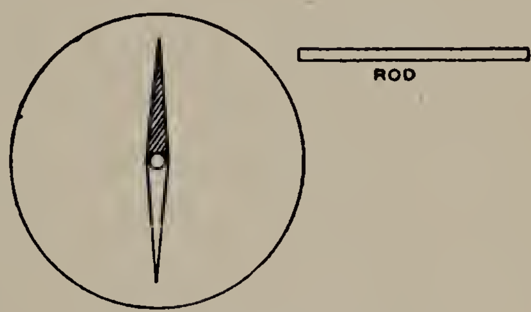
EXPERIMENT 80

MAGNETIC ACTION

How do magnets act toward each other? What is the law regarding magnetic poles?

What to do:

(*a*) Secure a soft iron rod (an iron nail will do) and a magnetoscope (a pocket compass will answer). Allow the needle of the compass to come to rest. It may not point true north and south; this will be due to some nearby piece of iron or another magnet, but will not interfere with your experiments. Approach, at right-angles, the north end of the compass with one end of the unmagnetized rod and note the result. Approach the south end of the compass with the *same* end of the rod and note the result.



TESTING FOR MAGNETIZATION.

FIG. 64.

(*b*) Now repeat with a magnetized nail or the watch spring of the previous experiment and record your results in the following table.

Pole of		Result
Magnet	Compass	
North-seeking....................	North-seeking...	
South-seeking....................	North-seeking...	
North-seeking....................	South-seeking....	
South-seeking....................	South-seeking....	

(*c*) From the results obtained above, state the *law of magnetic action.* What is the test for magnetization and why?

Materials Required.—Iron rod or nail; magnetoscope or pocket compass.

EXPERIMENT 81

RESULT OF BREAKING A MAGNET

What is the molecular theory of magnetization?

What to do:

(*a*) Secure a piece of watch spring 4 or 5 in. long. Magnetize it and then break it into several pieces being careful to keep them in their original order and position as when whole. Test each piece for polarity and mark the poles of each piece. Make a sketch of the original spring showing the polarity and then underneath it a sketch of the subdivided spring showing the polarity of each subdivision. How far could this dividing go on?

(*b*) Take a test-tube with enough filings in it to cover its length when held in a horizontal position. Magnetize this as you did the watch spring. Test it now for polarity, being very careful not to disturb the position of the filings. Now shake the tube and test again for polarity. Suppose that each little filing represents a molecule. What would be the position of its poles with respect to those of the adjacent molecules—first, when the body is magnetized; second, when the body is demagnetized?

Materials Required.—Piece of watch spring, a magnetoscope or compass; filings; and a small test-tube.

EXPERIMENT 82

MAGNETIC INDUCTION

Can a body be magnetized with or without contact by means of another magnetized body?

What to do:

(*a*) Secure an unmagnetized rod or nail and suspend it in a stirrup made by cutting a piece of paper diamond-shaped, the short diagonal having the length of the rod. Fasten a horseshoe magnet in a wooden clamp in a vertical position and place it under the suspended stirrup containing the iron rod.

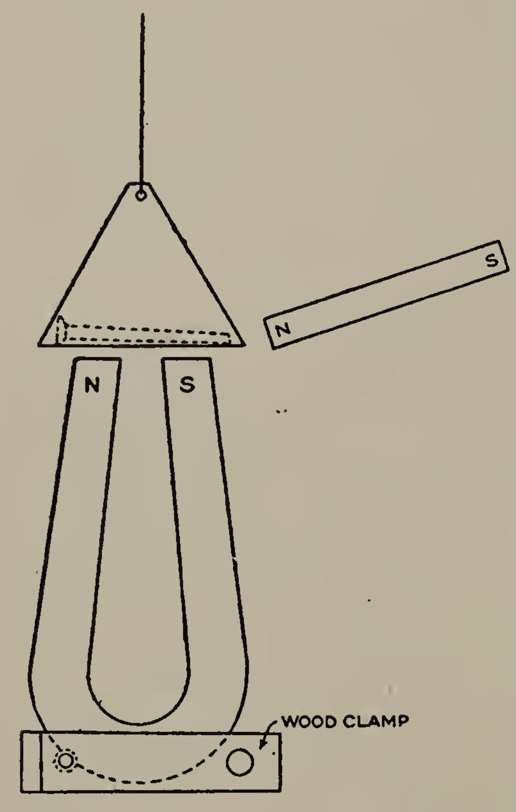


FIG. 65.

(*b*) Now bring the north end of a bar magnet near to one end of the nail or rod, just as you did the magnetoscope in the previous experiment, and note the result. Try again using the other end of the bar magnet. Reverse the rod in the stirrup and try again. Remove the rod from the stirrup and test it for magnetization.

(*c*) Put one end of the rod into some iron filings and your thumb over the other. Now put the pole of a bar magnet on top of your thumb nail and note the action of the filings. Now raise the rod up out of the filings keeping the magnet on top of the thumb. Now take the magnet away and

note the action of the filings. Test the rod for magnetization. Repeat, using a piece of paper in place of your thumb.

(*d*) From your results determine when and only when does the rod act like a magnet. Magnets made in this way are known as *induced magnets* and the method by which they receive their magnetization is known as *magnetic induction.* Now test the polarity of an induced magnet and compare it with that of the inducing magnet.

Materials Required.—A bar and a horseshoe magnet; nail or soft iron rod; clamp to hold horseshoe magnet; and a paper stirrup.

EXPERIMENT 83

MAGNETIC FIELDS

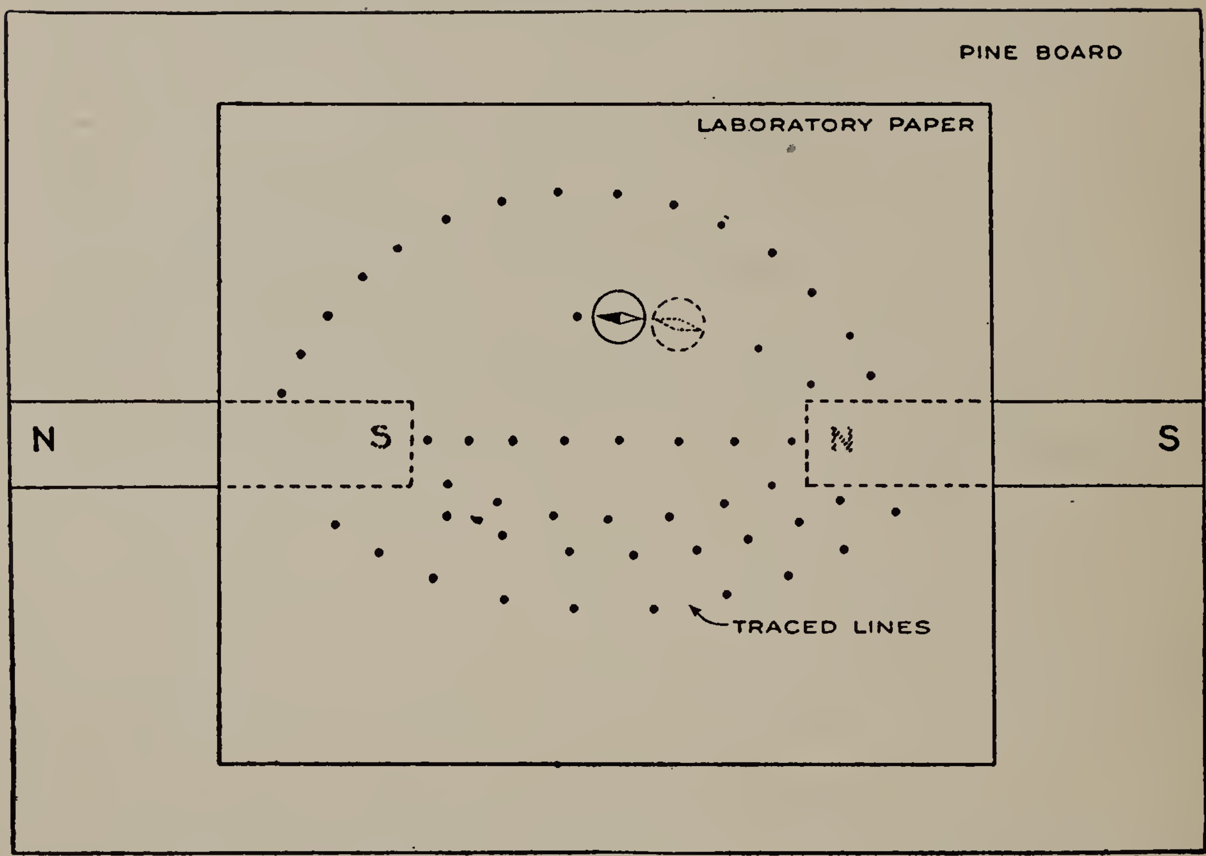


Fig. 66.

What is a *magnetic line of force?*

What is a *magnetic field of force?*

What to do:

(*a*) Place two bar magnets in line with each other with unlike poles about 6 in. apart, as shown in the diagram.

(*b*) Put over them a piece of laboratory paper so that each magnet is about half covered. Hold the paper in place with non-magnetic weights or pins. Draw the outline of the magnets and mark the poles.

(*c*) Now place a small compass near one of the magnets and between the two. Put a dot on the paper at each end of the compass needle. Now slip the compass along so that the end of the needle which was at the first dot

covers the second dot made and locate a third point. Slip the compass along in this way, locating points until the other magnet has been reached. Join the series of points thus obtained with a smooth line, without taking the paper from the table or disturbing the magnets. The line which you have just drawn is called a *magnetic line of force.* Trace about twelve such lines on the paper, spreading them over the whole paper.

(*d*) Make another chart but with like poles facing each other.

(*e*) Now place a piece of soft iron between the magnets and trace the field as before being sure that some of the lines pass through the piece of iron.

(*f*) The space surrounding a magnet in which lines of force can be detected is known as *a magnetic field.* A better idea of this field of force can be obtained by placing a piece of paper over the magnets and sprinkling it with iron filings and then tapping it gently with a pencil. The filings will arrange themselves according to the lines of force surrounding the magnet. A permanent record of these fields of force can be obtained by using a piece of blueprint paper instead of the ordinary laboratory paper.

Questions.—What form of field do you get when like poles are facing each other?

What kind when unlike poles face each other?

What is the effect of placing a piece of soft iron in a magnetic field?

Note.—If thick pine boards about 18 by 10 in. are available, the magnets can be sunk into them so that they are flush with the surface of the board. The paper will then lie perfectly flat and can be held down by means of pins or thumb tacks.

Materials Required.—Two bar magnets; a small compass (10 mm. is preferable); a piece of soft iron (an iron washer will do); and some iron filings.

EXPERIMENT 84

ELECTROSTATICS

FRICTION PRODUCES ELECTRIFICATION

What is the law of electrostatic charges?

What to do:

(*a*) Rub a piece of sealing wax, a vulcanite rod (hard rubber), or a glass rod briskly with a flannel cloth. Bring it near to some small bits of paper or dry sawdust. Some of the particles will be attracted by the rod and cling to it.

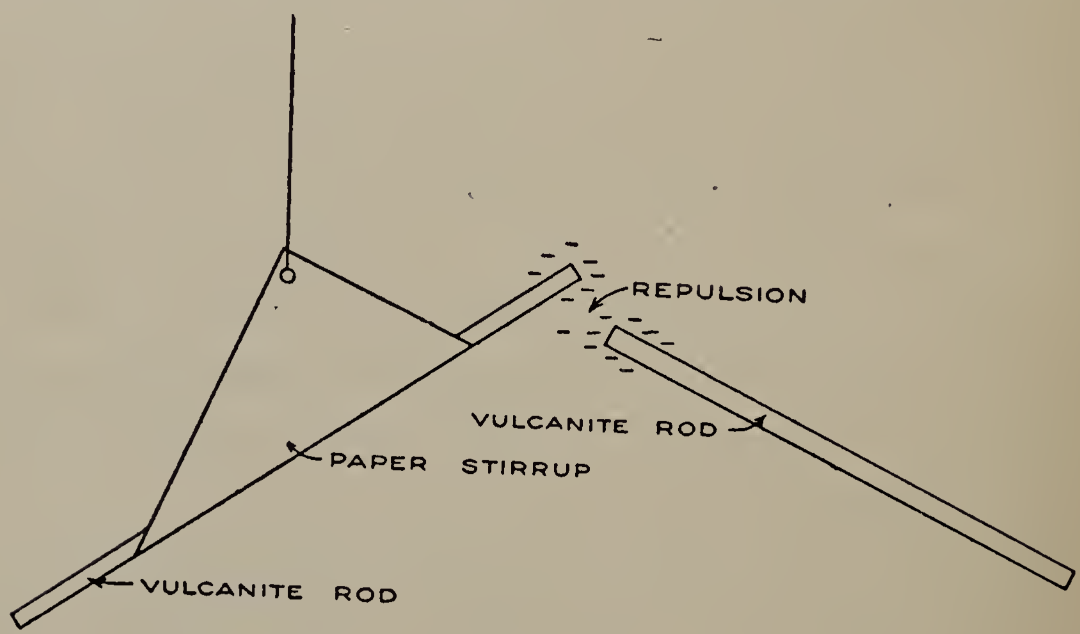


FIG. 67.

This is due to the fact that the rod has become *electrified* by the rubbing, or better by friction. Jar the rod slightly. The small particles will now leave the rod like kernels of corn being popped. Explain this action after having suspended an electrified vulcanite rod in a paper stirrup and approached it with another charged vulcanite-rod.

Repeat this test with two glass rods rubbed with silk. Try again using one glass rod and one vulcanite rod. Results?

(*b*) Do the charges on the glass and vulcanite rods appear to be the same or are they of a different character? To determine this more definitely make a *pith-ball electroscope* by suspending a pith ball from a support by means of a silk thread. Approach this suspended ball with a charged vulcanite rod. The ball will be attracted. Allow the ball to touch the rod and then try to approach it as before. Repeat, using a charged glass rod instead of the vulcanite rod.

(*c*) Now charge the pith ball with a vulcanite rod. Approach the ball with a charged glass rod and note the result.

(*d*) Charge the pith ball as in paragraph (*c*). Rub a vulcanite rod with a flannel cloth. Approach the ball with the cloth. Is it electrified? Rub a piece of glass with a silk cloth and test it in the same manner.

(*e*) It is assumed that when glass is rubbed with silk a positive charge is produced on the glass, and that when vulcanite is rubbed with flannel a negative charge is produced on the vulcanite. If the glass receives the positive charge, where is the equal and opposite negative charge?

(*f*) Charge a pith ball from a vulcanite rod. Approach it with a body which has not been rubbed, *a neutral body*, and determine its action.

Questions.—From your results determine what is the true test for electrification.

How can you determine the character of the charge on an electrified body?

How can you charge an electroscope positively? How negatively?

Note.—After completing each test you should neutralize the pith ball by touching it with your finger.

Materials Required.—Glass and vulcanite rods; pieces of flannel and silk; paper stirrup; and pith-ball electroscope. (Pith can be secured from the heart of dry corn stalk or sunflower stalks.)

EXPERIMENT 85

CONDUCTION

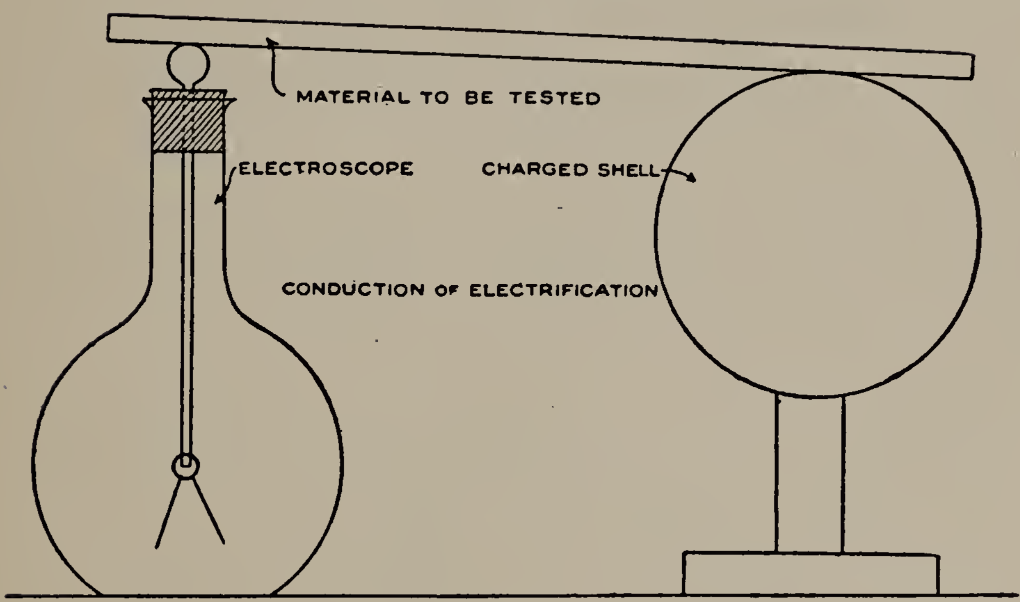


FIG. 68.

Is it possible to carry a charge from one object to another?

What to do:

(*a*) Support some substance such as a glass rod so that one end rests on the top of an aluminum-foil electroscope and the other end rests upon an insulated shell. (This can be any rather large conductor; a curtain-rod sphere mounted on an insulator is very desirable.) Rub a vulcanite rod with a flannel cloth. Touch the metal sphere with the charged rod, in other words transfer the charge to the metal sphere, and note whether or not the leaves of the electroscope are affected. Do not rush your work. Wait a few minutes so as to be sure of your results. After you are positive of the action touch the sphere with your

finger and again note the action of the leaves of the electroscope.

(*d*) Now remove the glass rod from its supports and put into its place, in turn, as many different substances as are available. Record your results in a table similar to that given below. You will find three general classes of substances: Some which respond almost immediately, these are called *conductors;* some which do not respond at all, these are called *insulators;* some which act very slowly, these are called *partial conductors.*

You should try rods of iron, brass, lead, copper, glass, vulcanite, wood, sealing wax, porcelain, also thread and paper.

Conductors	Insulators	Partial conductors

Questions.—How can you distinguish between an insulator and a conductor?

Which of the three groups do you consider most valuable?

Materials Required.—Rods of iron, brass, lead, copper, glass, vulcanite, wood, sealing wax, porcelain; piece of thread; a strip of paper; aluminum-foil electroscope; insulated shells; and pieces of flannel.

EXPERIMENT 86

INDUCTION

Is it possible for a body to become electrified without coming into contact with a charged body?

What to do:

(*a*) Secure an aluminum-foil electroscope. Touch the knob with your finger to be sure that it is neutralized. What kind of charges do neutral bodies have?

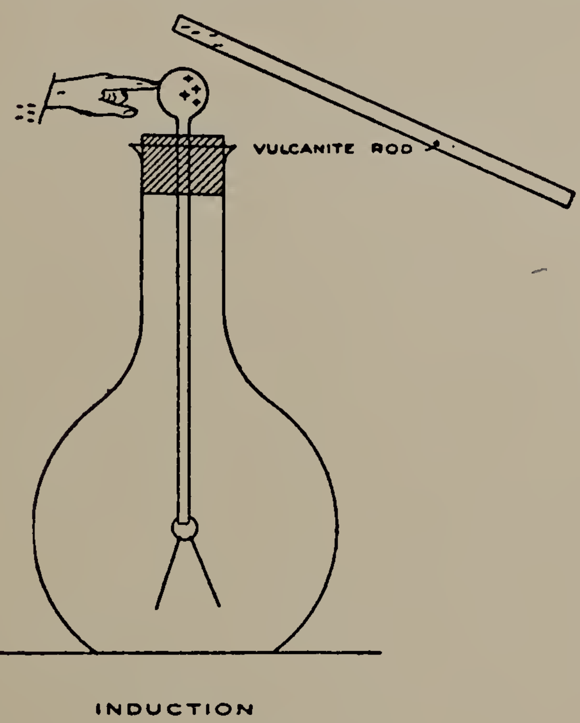


FIG. 69.

(*b*) Now rub a vulcanite rod with a flannel cloth. What kind of a charge does it possess and how do you know? Bring the charged rod near to, about ½ in. from the knob of the electroscope. Do you find any action? Remove the rod and note the result.

(*c*) Now approach the electroscope as you did before

and while the rod is so held, touch the knob of the electroscope with the forefinger of your left hand. Be very careful not to touch the vulcanite rod because this will spoil your test. See diagram. Remove your finger and then the rod. The leaves of the electroscope will now remain open. What kind of a charge is there now upon them? How do you explain this electrification? How does the charge on the leaves of the electroscope compare with that on the rod? A body which is charged as the electroscope just has been, that is, by being placed in an electric field, is said to be charged *by induction.* What is the real test?

Materials Required.—An electroscope; vulcanite or glass rod; and pieces of flannel and silk.

EXPERIMENT 87

THE ELECTROPHORUS

Of what practical value are condensers?

What to do:

(*a*) Secure an electrophorus. (A simple one may be made by putting some paraffine into an ordinary pie-plate and using for the upper conductor an insulated metal disk.) Place the electrophorus on the table and slap the wax plate with a flannel cloth. What does this do to the wax plate? Now place the metal disk down firmly upon the wax plate allowing it to rest a few seconds. While in this position touch the disk with your finger.

(*b*) Now remove the disk and test it for electrification by means of a charged electroscope. Is the disk charged? By what process? What is the character of the charge?

(*c*) Now bring the charged disk near to your hand. What is the result? Charge and discharge the disk several times. Do you note any falling off of the strength of the charge? How do you account for this?

(*d*) Secure a Leyden jar. How does it differ from the electrophorus? How are they alike? Charge the Leyden jar by discharging the electrophorus into it several times. After you have thus charged the Leyden jar put the little finger of your right hand in contact with the outer coating of the jar and approach the knob of the condenser with the thumb. What is the result? Is the charge thus received any different from that obtained from the metal disk of the electrophorus? Why? Explain.

Questions.—What is the main function of condensers?

Where and why are they used?

Give a simple definition for a condenser.

Must the dielectric always be glass?

Materials Required.—An electrophorus; a Leyden jar; electroscope; and flannel cloth.

EXPERIMENT 88

CURRENT ELECTRICITY

THE VOLTAIC CELL

What are the essentials of a volatic cell and of what use are they?

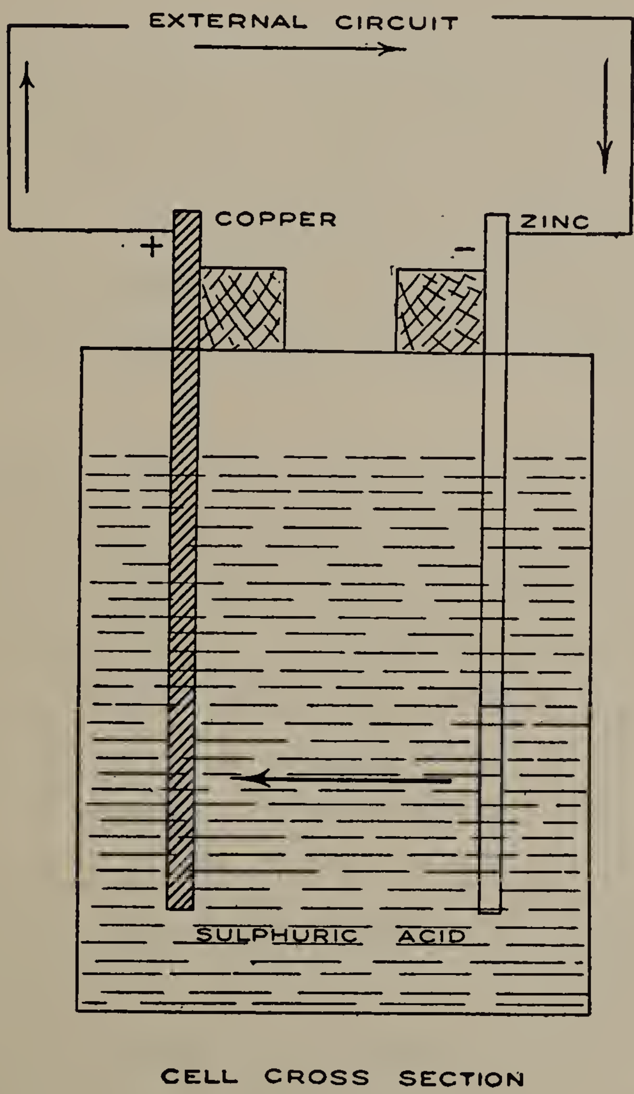


FIG. 70.

What to do:

(*a*) Secure a strip of copper and a strip of zinc, each about 1 in. wide and 5 in. long, and a tumbler or battery

jar three-fourths full of dilute sulphuric acid. For safety's sake, this should always stand in another dish partly filled with water as the acid will soil your clothes or the table top if any acid is spilt on either.

(*b*) Brighten up both the zinc and the copper strips by means of a piece of fine sandpaper. Put the zinc plate into the acid and note any action which takes place. Remove this, placing it into the water of the shallow pan, and place the copper strip into the acid.

(*c*) Now put in the copper and the zinc strips, keeping them about an inch apart. Note the result. Bring together the two wires fastened to the top of the plates and note any change in the action. Touch the two wires to your tongue. What do they taste like? From which wire do you get the better result?

(*d*) Repeat the above work using a zinc plate which has been amalgamated (that is a plate which has been covered with mercury).

(*e*) A voltaic cell consists of two dissimilar metals (electrodes) immersed in an electrolyte (any solution which will carry a current). In this case the two electrodes are copper and zinc and the electrolyte is sulphuric acid. The two electrodes are called the *anode*, the plate by which the current goes into the cell, and the *cathode*, the plate by which the current goes out of the cell. The electrode which wastes away more rapidly is the plate at which the current originates and is marked as the negative (−) plate. The current travels from this plate through the electrolyte over to the other or positive (+) plate. Since the current leaves the cell at the positive plate this plate is the cathode, and since the current enters the cell at the negative plate this plate is the anode. The current leaves the cell at the positive plate, travels out over the line or external circuit and finally returns to the negative plate.

The method of indicating cells in diagrams is by two lines close together of different lengths and thicknesses. A short heavy line indicates the negative plate and a long thin one the positive plate.

NOTE.—For convenience in the laboratory the strips of copper and zinc can be fastened to small pieces of wood long enough to span the top of the jar used and can have soldered to them short pieces of bell-wire.

Amalgamating fluid can be made by dissolving 15 c.c. of mercury in a mixture of 170 c.c. nitric acid and 625 c.c. of hydrochloric acid. This solution should always be kept in a glass bottle. To use, place the zinc in the liquid for a short time. Remove and wash in clean water. If this solution is not convenient, dip zinc in dilute sulphuric acid and rub over with mercury.

Materials Required.—Battery jar or tumbler; sulphuric acid; strips of copper and zinc; piece of sandpaper; and a shallow dish; amalgamating fluid or a little mercury.

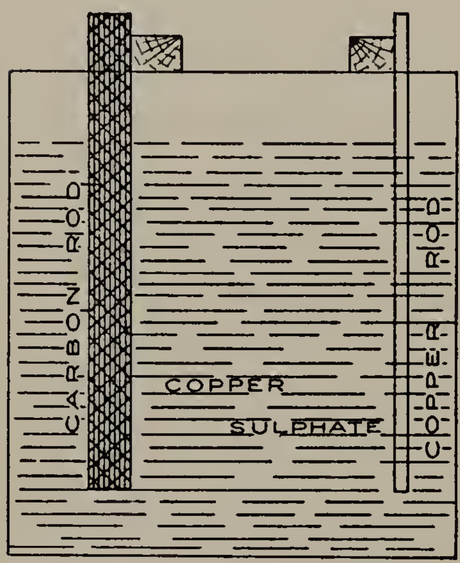
EXPERIMENT 89

ELECTROLYSIS

From where does the metal come which is deposited during the decomposition of an electrolyte by means of an electrical current?

What to do:

(*a*) Connect an electrolytic cell consisting of a tumbler three-fourths full of a solution of copper sulphate, a copper plate, and a carbon plate, in series with a source of direct current (a good dry cell) and a means of breaking the circuit (a push button will do). The cell should be so connected that the positive wire of the battery or line is connected to the copper plate of the electrolytic cell.



ELECTROLYTIC CELL

FIG. 71.

(*b*) Close the circuit by pushing the button. Allow the current to flow through the cell for a few minutes. Remove the carbon rod from the solution and examine it carefully. What is the character of the deposit? Is it uniform? Examine the copper plate. Has it changed? From your observations determine where the copper which has been deposited on the carbon rod came from and how this was accomplished. On which plate of the electrolytic cell was the deposit made, the anode or the cathode? The anode of an electrolytic cell is the electrode through which the current

enters the cell and is connected to the positive wire. The cathode is the electrode through which the current leaves the cell and is connected to the negative wire.

(*c*) Now reverse the wires on the electrolytic cell, that is, put the wire which was fastened to the carbon plate on to the copper plate, and the wire which was on the copper plate on to the carbon plate. Close the circuit as before and allow the current to flow for several minutes. Again examine the two plates carefully and note any change which may have taken place.

(*d*) On a piece of white blotting paper put a few drops of potassium iodide. On this place, close together, wires from three dry cells connected in series. Now move them slightly. One of the wires will leave a brown mark on the paper. Note which one this is, the positive or the negative.

(*e*) Copper is a metal and iodine a non-metal. What is your conclusion as to the direction in which metals and non-metals travel during the process of electrolysis, with the current or against it?

Electroplating is the process of depositing a metal on an object from a solution of that metal by means of an electrical current.

Questions.—Name some of the metals which are generally deposited by this process. Have you any objects in your home which have been electroplated? Name them. Is there any commercial use for the electrolytic process?

Materials Required.—Glass tumbler, solution of copper sulphate; plates of copper and carbon; three dry cells; push botton; piece of bell wire; solution of potassium iodide, and a piece of blotting paper.

Note.—The copper deposit on the carbon plates can be removed by placing them in strong nitric acid. This will dissolve out the copper and the plates can again be used.

EXPERIMENT 90

THE COPPER VOLTAMETER

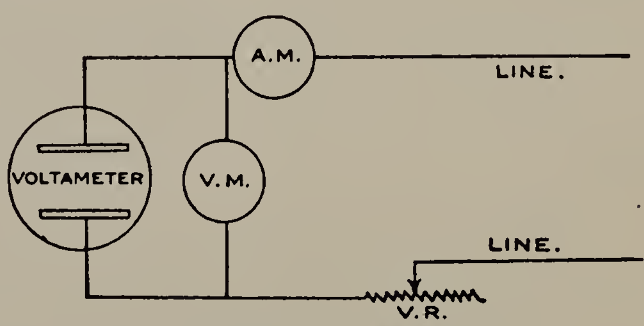
Of what practical value is any voltameter?

What to do:

(*a*) This is a practical application of the electrolytic process. Use the electrolytic cell of the previous experiment as a voltameter. Make up a standard solution of copper sulphate as follows.

Copper sulphate	150 grams.
Sulphuric acid	50 grams.
Alcohol	50 grams.
Water (distilled)	1,000 grams.

(*b*) Weigh the carbon plate or rod very carefully on a beam balance. Then connect the voltameter in series



THE COPPER VOLTAMETER.

Fig. 72.

with an ammeter (A.M.) and a source of direct current (see Fig. 72). Adjust the current by means of a lamp bank or variable resistance (V.R.) to read about three (3) amperes. Allow the current to flow for 1 hour. Remove the carbon plate. Dry in a current of air or by holding about 2 ft. above a Bunsen burner and then weigh as before.

The weight in grams of material that is separated from an electrolyte by 1 amp. of current in 1 second (the coulomb) is called its *electro-chemical equivalent.*

$$\text{Electrochemical equivalent} = \frac{\text{weight (grams)}}{\text{time (seconds)} \times \text{current (amperes)}}$$

The copper voltameter gives one method of ammeter calibration. Connect the voltmeter as shown to get the drop across cell. With this reading the resistance of the cell can be obtained.

Find the weight of copper deposited by subtracting your first reading from the one just obtained. From your results find the electro-chemical equivalent of copper. Theoretical value = 0.000329. Find your per cent. of error.

Materials Required.—Electrolytic cell of the last experiment; standard solution of copper sulphate; voltmeter; ammeter; source of direct current and a means to regulate same.

EXPERIMENT 91

MAGNETIC EFFECT OF CURRENT-CARRYING WIRES

How can you prove that there is a magnetic field surrounding a wire which carries a current?

What to do:

(*a*) Secure a dry cell, a push button, about 2 ft. of bell wire, and a compass. Now connect the cell and push button together.

(*b*) Hold a single length of wire between your hands so that it runs in a north and south direction. Make your connections to the battery so that the current flows through the wire from north to south; that is, the wire which is connected to the carbon element of the cell should be fastened to the north end of the wire.

(*c*) Place the wire so held directly over your pocket compass or about an inch above the needle of a magnetoscope. Close the circuit by pushing the button and note the effect on the needle. Note the direction in which it turns.

(*d*) Holding the wire as before, place the compass on top of it and note the direction in which the needle turns.

(*e*) Still keeping the wire in the same position, reverse the wires of your battery; that is, fasten the wire which was connected to the zinc on to the carbon, and the wire which was fastened to the carbon on to the zinc. With these connections first hold the compass above and then below the wire and note the result in each case. Record your results in the following form:

Direction of current	Deflection of compass
North to south—above....................	
North to south—below....................	
South to north—above....................	
South to north—below....................	

(*f*) Now tilt your compass on edge and move it around the wire carrying the current. What do you find? Grasp the wire with the *right* hand so that the fingers point in the direction of the lines of force. Does your thumb point in the direction in which the current flows or in the opposite direction? From the answer to this question we derive the *right-hand rule* for a straight conductor carrying a current. State it.

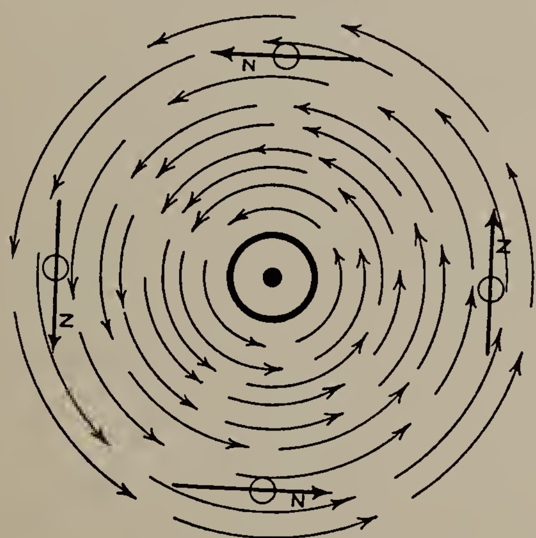


FIG. 73.

(*g*) Fig. 73 shows a compass in the lines of force about a conductor in which the current is coming toward you. Make a similar diagram to show the conditions with the current going away from you. Show this direction of current by placing a cross (x) in the center of the conductor section.

(*h*) What would be the effect on the compass if we had a loop of wire instead of the single conductor? What if we had a coil of wire?

(*i*) Fig. 74 shows the fields about two parallel wires carrying current in the opposite direction. Make this

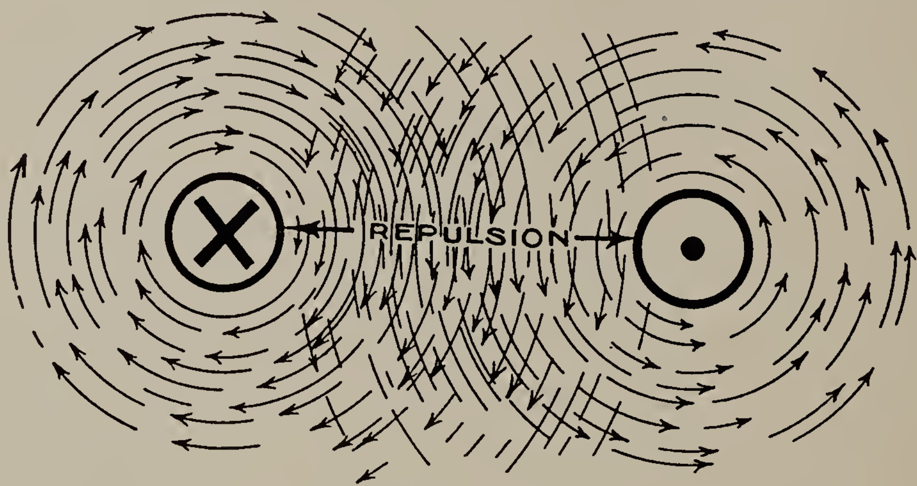


Fig. 74.

diagram and also another to show the condition when they carry current in the same direction.

Materials Required.—Dry cell; push button; several feet of bell wire; and a pocket compass.

EXPERIMENT 92

ELECTROMAGNETS

Where are electromagnets used and how do they receive their magnetization?

What to do:

(*a*) Secure a strand of No. 22 cotton-covered wire or a strand of bell wire about 3 ft. long, also a soft bar of iron 3 in. long (a large soft iron nail will do). Wind the wire upon the rod keeping the turns close together and wind on two layers.

(*b*) Connect the coil in circuit with a dry cell and push button. Dip the end of the rod (now the core of the electromagnet) into some iron filings and close the circuit by pushing the button. What is the result?

(*c*) Note very carefully the direction in which the current is flowing through the coil. Approach one pole of a compass with one end of the core. What is the effect? Try the opposite end of the compass needle with the same end of the core. Now try the other end of the core in the same way. From your results what is the polarity of the coil with reference to the direction of the current?

(*d*) Now change your battery connections and repeat the last paragraph. Do you find any change in the conditions of the coil?

(*e*) Suppose you grasp the coil of wire in your right hand so that your fingers point in the direction in which the current is flowing through the coil, toward which pole of the magnet does your thumb point? The above law

is the right-hand rule for a helix. Give a complete statement of it.

(*f*) Make a good diagram of an electromagnet indicating the direction of the current and mark the poles.

(*g*) What would be the effect if the electromagnet had a larger number of layers of wire or, better, more turns? Try it and see.

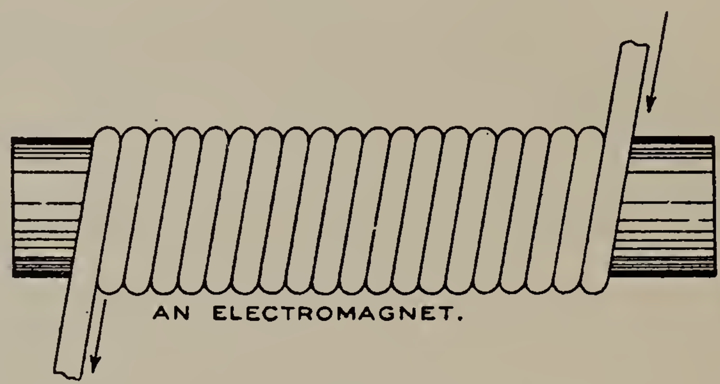


FIG. 75.

Questions.—How long do electromagnets retain their magnetization?

What does an electromagnet consist of?

Upon what does the strength of the magnet depend?

Materials Required.—Pocket compass; soft iron rod; a few feet of bell wire; a dry cell; a push button; and some iron filings.

EXPERIMENT 93

ELECTROMAGNETIC FIELDS

Where are electromagnetic fields used and how do they differ from those of permanent magnets?

What to do:

(*a*) Cut from a piece of sheet iron which is about 6 in. square and about 1/16 in. thick, a shape similar to that indicated in the diagram. You now have substantially

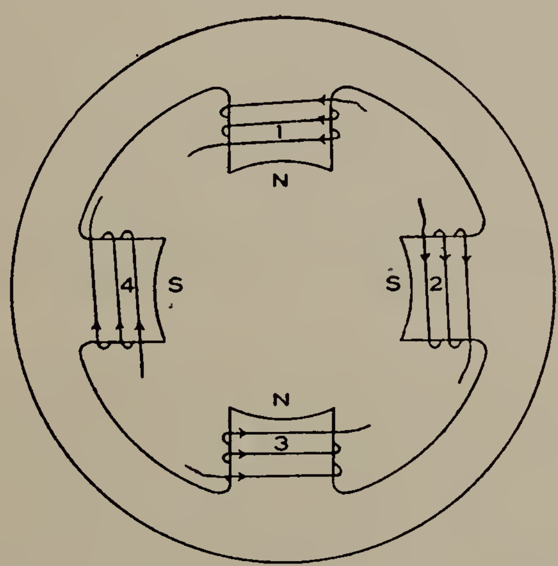


FIG. 76.

the frame of a four-pole dynamo. The parts 1-2-3-4 are called the *pole pieces* and the circular section connecting them is known as the *yoke*.

(*b*) Wind on the pole pieces about 12 turns of wire. Join all four coils in series with each other, that is, the end of the first is to be fastened to the beginning of the second and so on. Now connect the coils in circuit with a battery of dry cells or a storage battery being careful to connect

the beginning of coil one to the positive pole of the battery and the end of coil four to the negative pole of the battery.

(*c*) Lay the outfit on the table. Close the circuit and by means of a compass determine the polarity of each of the pole pieces. The first and third should be north and the second and fourth should be south. If this is not true, change the connections so that it is.

(*d*) Place over the coils a sheet of laboratory paper and sprinkle iron filings over it. Close the circuit and tap the paper with your pencil gently. You will now have a record of the lines of force. A permanent record can be made by using a piece of blueprint paper instead of the laboratory paper.

(*e*) Reverse the connections of two opposite coils and repeat the last paragraph.

(*f*) Now place a piece of iron in the center of the chart equally distant from all pole pieces. Make a field as before and note the effect of the iron on it.

Questions.—How can the polarity of a four-pole dynamo be determined?

Can all the field coils be wound in the same direction?

If they are all wound in the same direction, how is it possible to have every other pole reversed?

Materials Required.—A piece of sheet iron; tin shears; several feet of bell wire; two dry cells; a push button; iron filings; some blueprint paper, if permanent records of the fields are desired; and a pocket compass.

EXPERIMENT 94

THE BUZZER

How should buzzers be connected if several are to be used on the same circuit?

Introductory:

The action of the buzzer is as follows. Current enters at binding post, *A*, which is generally insulated from the frame by means of a fiber or rubber washer, and passes from this, first through one of the coils and then the other. From these it passes to the set-screw, *R*, also insulated from the frame, and into the brass spring, *S*, fastened to the armature. From this spring the current goes to the second binding post, which is fastened directly to the frame. From here it returns to the cell or other source of current. When the circuit is closed and

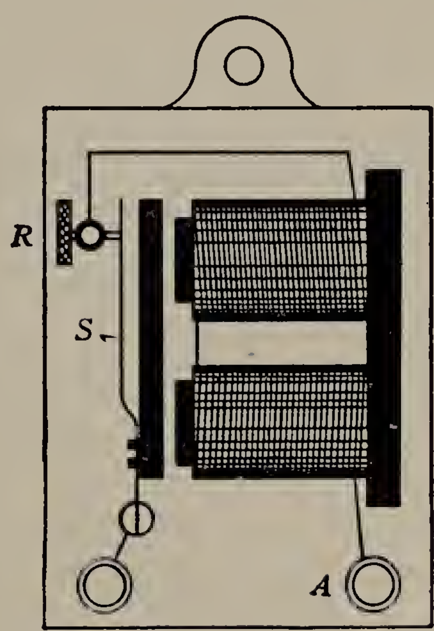


FIG. 77.

current flows through the coils, they become magnetized and attract the iron armature, but in so doing they separate the set-screw and the brass spring, thus opening the circuit. When this happens the coils become demagnetized and can no longer hold the armature. Since the armature is under tension of the spring it again returns to its normal position resting against the set-screw. However, the moment this occurs the circuit is again complete, the coils are magnetized, and the armature is drawn toward them

against the action of the spring. This operation is repeated in rapid succession and continues as long as the external circuit remains closed, giving forth a peculiar buzzing noise.

The commercial form of electric bell has a hammer or weight attached to a small rod which is fastened to the armature in such a way that when it is drawn over against the electromagnets this weight or clapper strikes a gong or bell.

What to do:

(*a*) Secure a bell or buzzer and connect it in series with a push button and a dry cell. Examine its construction very carefully noting the insulation, set-screw, spring, and magnet coils. Make a diagram of a buzzer similar to that shown in the figure and indicate on it the direction of current and indicate the polarity of the electromagnets.

(*b*) Make diagrams, using a single battery in each case, to indicate:

One bell operated by one push.

Two bells operated by one push.

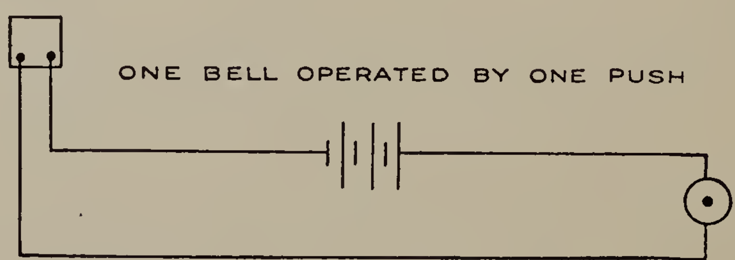


Fig. 78.

Two bells operated by two pushes—bells to ring separately.

Three bells operated by three pushes—bells to ring separately.

Materials Required.—Three electric bells or buzzers; three push buttons; several pieces of bell wire; and two dry cells, or other source of current.

EXPERIMENT 95

RESISTANCE

Upon what items does the resistance of a conductor depend?

What to do:

(*a*) Connect about 4 ft. of No. 28 German silver wire in series with an ammeter (0 to 10 amp.) and a good dry cell. Note the deflection of the ammeter. Now take 8 ft. of the same wire and connect as before and note the deflection. How do these two readings compare? From your results, what relation exists between the resistance of a conductor and its length? Now connect in the circuit, the same length of No. 22 German silver wire, which has very nearly four times the area of a No. 28 wire, and determine the reading of the ammeter. From this and the reading obtained above, what effect and relationship do you find between the size of wire and its resistance? For example, suppose you double the area of cross-section, in what ratio does the resistance change? Suppose you make the area four times as great, what is the effect on the resistance? Now connect 16 ft. of No. 22 German silver wire in the circuit. Compare this reading of the meter with that obtained for the copper wire of the same length and size. Now, judging from your results, what factors change the resistance of a conductor and in what way? Explain.

(*b*) Now secure a set of resistance spools or a variable resistance made up of various lengths of different kinds of wire. Connect these in series with a set of dry cells, a small switch (knife switch preferable) and an ammeter

(see Fig. 79). Close the switch and by means of a voltmeter determine the drop across each of the spools or wires.

(*c*) Record your results in the following tabular form and from them calculate the resistance of each by the

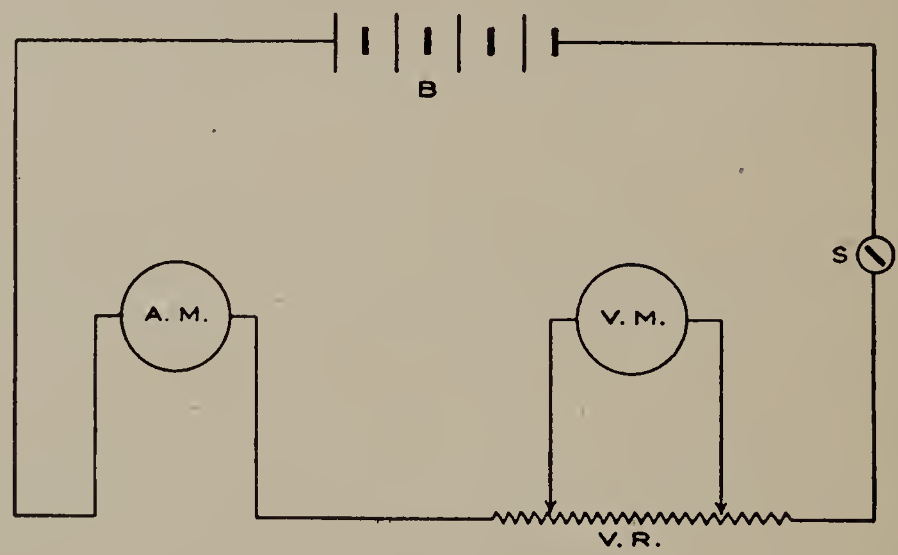


FIG. 79.

formula $R = E/I$ in which R = resistance, E = volts, and I = amperes. Compare this calculated resistance with that given in the B. & S. wire table (Table 6, Appendix).

Wire			Volts (E)	Amperes (I)	Resistance (R)	
Kind	Length	Diameter			Calculated	B. & S.

(*d*) Measure also the resistance of several commercial articles. This method of finding resistance is called the volt-ammeter method.

Materials Required.—Voltmeter (0 to 15 volts); several feet of No. 22 and 28 copper wire; German silver wire; three dry cells; a switch; and several commercial articles such as telegraph sounder, telephone receiver, or bells.

EXPERIMENT 96

CONDUCTOR SIZES

Of what value is a graph showing the relation between any given area and the corresponding B. & S. wire size?

What to do:

(*a*) Secure from the instructor a variety of wires, rods, sheets, and stranded cables such as are commonly used as conductors of electricity. Determine the sizes of the various conductors first by means of a *wire gauge* and then by means of a *micrometer caliper*. Record your results in tabular form and from them calculate the area in circular mils and also in square mils.

The mil is one-thousandth of an inch.

The circular mil is the area of a circle 1 mil in diameter.

One square mil = 1.273 circular mils.

Material	Size		Gauge error	Area	
	Wire gauge	Caliper		Square mils	Circular mils

(*b*) Plot graphs to show the relationship between:

1. B. & S. sizes and areas (circular mils).
2. B. & S. sizes and diameters (mils).

(*c*) What definite relation do you find between the different sizes of wire?

Why is the size of the conductor of such great importance in the electrical work?

Why would not a rectangular conductor do just as well as a circular one for house wiring?

Where are rectangular conductors used and why?

NOTE.—See Appendix, Table 6.

EXPERIMENT 97

FUSE WIRE TEST

Upon what law does the operation of a fuse depend?

What to do:

(*a*) Connect the adjustable fuse block in series with an ammeter and a lamp bank, for adjusting the current, and a double-pole, double-throw knife switch so arranged that the current can be brought up to any desired point before being thrown on to the fuse to be tested (see Fig. 80).

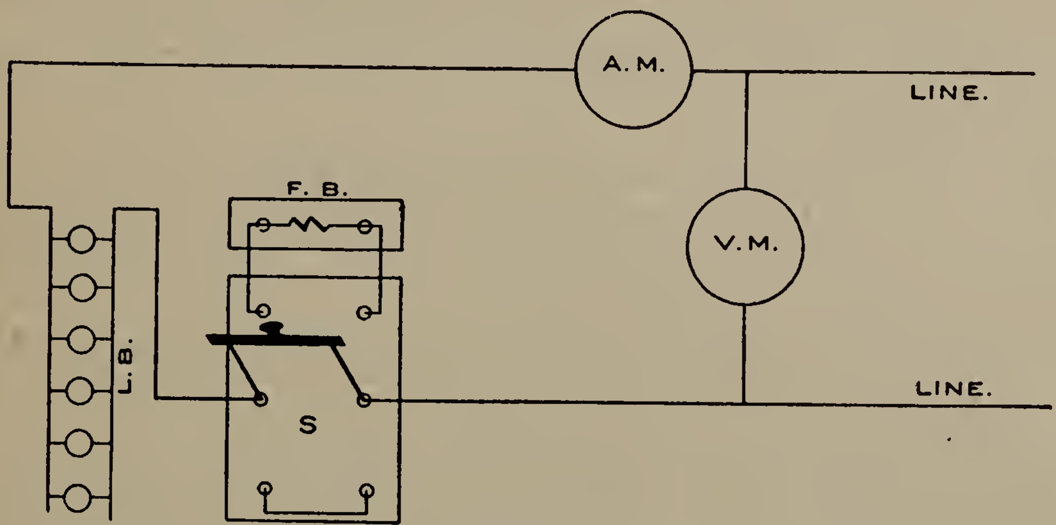


FIG. 80.

(*b*) Cut fuses from pieces of tin-foil of various lengths, and thicknesses, and widths. Measure these very carefully. Obtain the thickness by means of a micrometer caliper.

(*c*) Time test. Take one of the samples and place it in the fuse block. Adjust the current to some small value. Then throw the switch over so that the current passes through the fuse and by means of a watch determine the

exact time required to blow. If the fuse does not blow at the current selected, build it up step by step until a value is reached which will blow it. Make about twelve such tests and record your results in tabular form.

Kind of Fuse				
Test	Length	Area	Amperes	Time

(*d*) Length test. Cut as before about a dozen fuses whose width and thickness are the same but whose lengths are variable. Find the point at which these blow and record as before.

Now secure from the instructor several pieces of standard fuse wire of different capacities and determine the fusing point of these samples.

(*f*) Plot two graphs: one between current and time; the other between current and length.

Materials Required.—Ammeter; 110-volt circuit; lamp bank; adjustable fuse block; double-pole double-throw knife switch; pieces of tin-foil; and several lengths of standard fuse wire (3, 5, and 10 amp. capacity).

EXPERIMENT 98

LAMP-BANK CURRENT REGULATORS

What lamp gives the most light for the least power?

What to do:

(*a*) Connect an adjustable lamp bank, consisting of six lamps of different ratings, in series with an ammeter and a source of current. Connect a voltmeter across the line to determine the drop across it. From the marking on the lamps determine the following. The instructor will give you the candlepower.

Lamp	Candle-power	Volts	Amperes	Watts	Watts per candle

(*b*) Calculate the resistance and the power from the current at line pressure and record the results in the following tabular form:

Lamp	1	2	3	4	5	6	Total
Candlepower....................							
Current (I)....................							
Resistance (R)..................							
Power (W)....................							

(*c*) Resistance of combinations.

Lamps	Parallel			Series		
	Current	Resistance	Power	Current	Resistance	Power
1–2						
1–3						
1–4						
1–5						
1–6						

(*d*) What is a rheostat? From your observations when is the largest current obtained? Give lamp numbers, state connection, and give resistance. When is the smallest current obtained? Give data as before. Where is a rheostat used and for what purpose?

Materials Required.—An adjustable lamp bank, consisting of six lamps of different ratings; an ammeter; a voltmeter; and a source of current.

EXPERIMENT 99

THE WHEATSTONE BRIDGE

SLIDE-WIRE FORM

What practical use is made of the Wheatstone bridge in the commercial world?

Introductory:

The Wheatstone bridge consists of four resistances. Three of these are known variable resistances and the fourth is unknown. The value of this fourth resistance can be determined by a comparison with the other three. Suppose these resistances are designated by the letters, a, b, R, and X. Suppose they are connected up in a circuit with a dry cell and galvanometer as is shown in the sketch. G is a galvanometer, telephone receiver or zero-center ammeter, and K the slider or contact key.

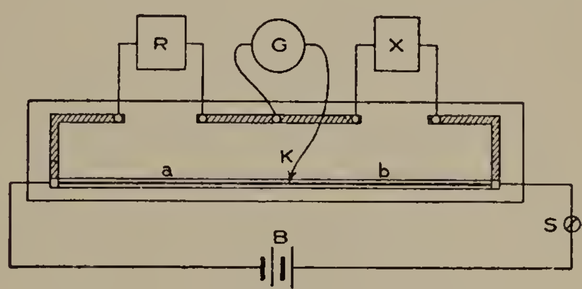


FIG. 81.

According to Ohm's law the fall of potential over a conductor is proportional to the product of the current and the resistance of that conductor. Then with any *given* pressure the current flowing in any circuit will be directly proportional to the resistance of that circuit. With these points in mind it must be true that $a \div R = b \div X$, if no current passes through the galvanometer, and if this is true the drop across its terminals is zero. However, if these are not equal the current will divide and part will

pass either up or down through the galvanometer. If a and b are of equal length and R is less than X then current will flow upward through the galvanometer; but if X is less than R then current will flow downward and the deflection will be in the opposite direction. Since the key is a sliding member it is possible with any predetermined value of R to move the key back and forth until the relation between $(a \div R)$ and $(b \div X)$ is such that the galvanometer shows no deflection. Since this is true, the values must be equal. When this is accomplished we have the following condition, $a : b :: R : X$ from which we derive $aX = bR$ or $X = \frac{bR}{a}$.

The resistance $a + b$ is generally made of a single wire of high resistance mounted on a graduated scale (a meter stick). Since this wire is of almost uniform cross-section, the resistance of a and b is proportional to their length.

What to do:

Find by means of the apparatus the resistances of a series of resistance spools and several commercial articals such as a flatiron, soldering iron, telephone receiver, incandescent lamp, or ammeter. Record your results in the following form.

Device	a	b	R	X

Materials Required.—Slide-wire bridge; dry cell; resistance spools; and commercial articles such as telephone receiver, ammeter, soldering iron toaster, or incandescent lamp.

EXPERIMENT 100

THE WHEATSTONE BRIDGE

POST-OFFICE FORM

Where would you use this form of bridge in preference to the slide-wire form?

Introductory:

This form of bridge has exactly the same principle of operation as the slide-wire form. It is different from

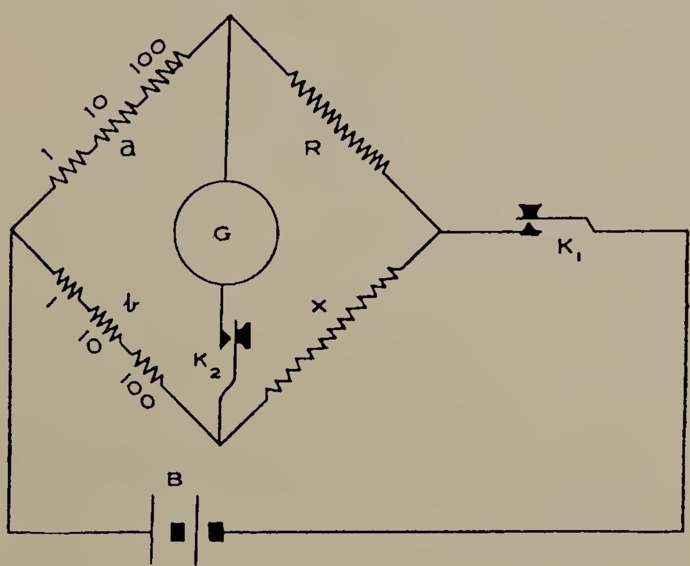


FIG. 82.

that form in that the resistances *a* and *b* are generally known as the ratio arms and in commercial forms have a variety of fixed predetermined values. The common ones are 1–10–100 ohms. This makes it possible to measure a resistance which is 1/100 part of the smallest value of *R* or 100 times as large as the largest value of *R*. Using a galvanometer as an indicator makes this method one of the most accurate for finding unknown resistances.

What to do:

(*a*) Connect up a bridge as indicated or use the standard form and find the resistances of the materials used in the last experiment. Try first an even ratio, that is make a and b equal. Remove from R the plug giving the lowest resistance. Now close contact keys K_1 and K_2 and note the direction of deflection of the galvanometer. Replace the plug and remove the one giving the largest value of R. Close the keys as before and note the deflection of the galvanometer. If the deflection is opposite to that of the small value of R you have the correct ratio arms and you can now proceed to find the value of X. Adjust R so that there is zero deflection or at least until the galvanometer points as much to one side of the zero as it does to the other when there is a difference of one plug made in either direction. If you do not get a reversal of deflection by removing first the smallest and then the largest value of R, your ratio is incorrect and you should try another.

(*b*) Having found the values of a, b, R, and X which give zero deflection substitute them in the formula given in the first paragraph of the previous experiment and calculate the value for X. Find the resistance of the various materials as listed in that experiment.

Materials Required.—Same as experiment 99, with post-office type of apparatus.

EXPERIMENT 101

CONDUCTIVITY OF COMMON ELECTROLYTES

Upon what factors does the conductivity of an electrolyte depend?

What to do:

(*a*) Connect the apparatus up as is shown in the sketch.

(*b*) Place the carbon rods or electrodes into the battery jar as far apart as possible. Fill the jar three-fourths full

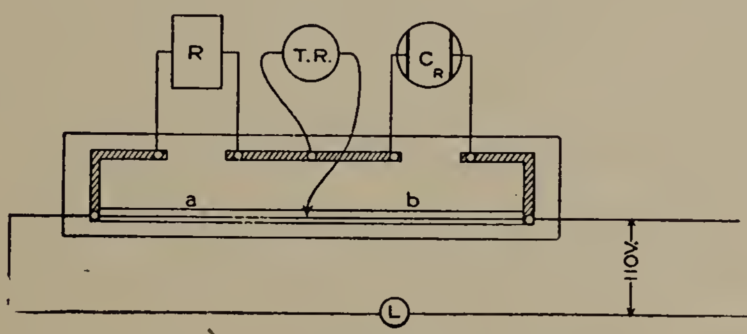


FIG. 83.

of a saturated salt solution. By means of the bridge obtain the resistance of this solution; call it C_R. In the same way, using always the same quantity of liquid and keeping the plates the same distance apart, find the resistance of about ten different degrees of dilution.

(*c*) Record your results in tabular form and calculate the conductivity ($1/C_R$) in each case.

Solution	a	b	R	C_R	$\frac{1}{C_R}$

(*d*) Find in the same way the conductivities of standard solutions of copper sulphate, sal-ammoniac, potassium dichromate, potassium hydrate, sulphuric acid, nitric acid, hydrochloric acid, and pure distilled water.

(*e*) Plot a curve showing the relation between conductivities and degrees of dilution, for several materials.

(*f*) Using any one of the above substances determine the change in the conductivity by varying the distance between the plates by steps of ¼ in.

(*g*) Plot a graph between conductivities and distance between plates.

Questions.—1. Name several places in which the conductivity of an electrolyte is of great importance. 2. Why is it necessary to use an alternating current in this experiment? 3. What do the curves indicate? Of what value are they? 4. Why must the plates be kept the same distance apart throughout the experiment?

Materials Required.—Quart battery jar, two carbon electrodes; several electrolytes; telephone receiver; slide-wire bridge; and a resistance box. Use as a source of current a 110-volt *alternating-current*, lighting circuit, which has a lamp connected in series to limit the flow of current.

EXPERIMENT 102

BATTERY TESTING

What is the better method of connecting primary cells, series or parallel?

What to do:

(*a*) After having connected the cell, voltmeter, and resistance box as is shown in the diagram, vary the resistance so that you will get about 12 or 15 readings for each cell. The time of each reading should be about 2 minutes and the contact key should be kept closed all the time except when a reading is being taken, and then only long enough to get the reading. After you have recorded your results in a table similar to that given below, calculate the internal resistance from the following formula:

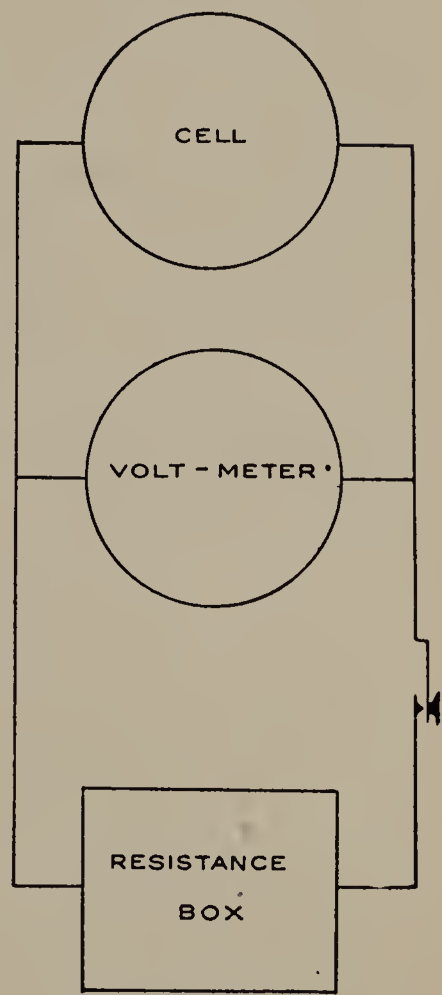


FIG. 84.

$$r = R\frac{E - E'}{E'} = \frac{E - E'}{I}.$$

Where r = internal resistance.
R = external resistance.
E = voltage without resistance.
E' = voltage with resistance.

(*b*) Make a graph showing the relation between the current and the internal resistance for each cell. Of what value are these data?

(*c*) Find resistance of two cell in parallel, and then in series.

(*d*) From your results determine which cell has the highest internal resistance? Which the lowest?

How would you connect cells in order to get the largest current from them?

How would you connect them to get the highest pressure?

If a certain given type of cell is to be connected to an external resistance which is high as compared to that of the cell, how would you connect them in order to get the greatest current? If the external resistance were low, how would you connect them? Give reasons for your answer.

Materials Required.—Voltmeter (0–5); resistance box (0.1–40); several primary cells of different makes; and a contact key or single-pole knife switch.

R	E'	$E - E'$	I	r

EXPERIMENT 103

THE STORAGE BATTERY

For what purpose is this cell best fitted and what advantage does it have over the ordinary cells?

Introductory:

Secure two lead plates about 1/16 to 1/8 in. thick and wide enough to fit a good-sized tumbler or battery jar. Fasten these plates securely to a strip of wood long enough to span the top of the jar and about 3/4 in. thick. Fill the jar three-fourths full with a dilute solution of sulphuric acid (1 part acid to 12 parts distilled water). Is there any action on the plates as there was in the simple voltaic cell experiment? Why?

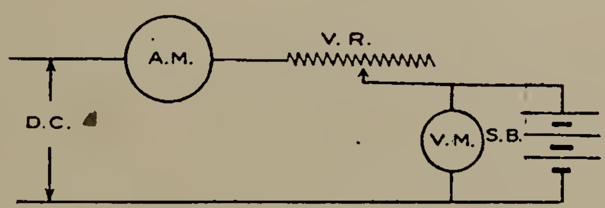


FIG. 85.

(*a*) Connect the cell in series with an ammeter and a source of direct current (see Fig. 85). Adjust the ammeter to read about 3 amp. Note carefully which plate of the cell is connected to the positive side of the line. Connect a voltmeter in parallel with the cell and make note of the pressure. Is there now any action on the plates? Allow the current to flow for a period of 2 minutes. Then disconnect the cell and allow it to rest for a minute or two. Test again with the voltmeter. What does it read?

Has the character of the plates changed any? Which plate is now positive? What side of the line was it connected to?

(*b*) Discharge the cell through a buzzer, door bell, or other resistance and note the time required to stop action. Now place the cell on charge again, being careful to have the plates in the same position as on the first charge. This time allow the cell to remain on charge for 5 minutes. Discharge as before and note any change in the plate character, voltage, and time required to discharge.

(*c*) How often do you suppose this operation can be repeated?

What is the maximum voltage obtainable from such a cell?

(*d*) A cell such as you have just been testing is called the "solid plate" or the "Planté" type. How does this differ from the commercial, the "pasted or Fauré'" type? In which direction does the current flow on charge? On discharge?

To illustrate the action of the "Edison" type of cell repeat this experiment using two rusty iron plates as the electrodes and a saturated solution of potassium hydrate (KOH) as the electrolyte.

Materials Required.—Two lead plates 1/16 or 1/8 in. thick and about 3 in. wide and 4 in. long; one quart battery jar; dilute solution of sulphuric acid (1–12); buzzer; voltmeter; ammeter; source of direct current and means of regulating same.

EXPERIMENT 104

DENSITY OF COMMON STORAGE-BATTERY SOLUTIONS

What does the density of the liquid in a storage cell indicate?

To bring this experiment within the limits of the ordinary class time, a simple lead-plate storage cell should be selected (see introduction of Experiment 103).

What to do:

(*a*) Connect the cell to a source of direct current as is shown in the sketch (see Fig. 85). Insert the hydrometer and note its reading. Now adjust the charging current to about 3 amp. Keep this current constant.

(*b*) Take readings of the hydrometer, voltmeter, and ammeter at 5-minute intervals until the cell gives off gas freely. The cell is now completely charged.

(*c*) Now discharge the cell through a rheostat or other device which takes about 3 amp., and again make note of the hydrometer, voltmeter, and ammeter readings every 5 minutes until the cell is discharged.

(*d*) Record your results in the table on p. 228.

(*e*) Plot a graph showing the relationship between the time and the density while on charge. Plot another graph for discharge.

Materials Required.—Voltmeter; ammeter; hydrometer; variable resistance; and a source of direct current, a simple lead-plate storage cell (see Experiment 103).

Time	Charge			
	Volts	Amperes	Resistance	Density
0				
5				
10				
15				
20				
25				
30				
	Discharge			
0				
5				
10				
15				
20				
25				
30				

EXPERIMENT 105

HEAT PRODUCED BY AN ELECTRIC CURRENT

Upon what factors does the heat produced in any electrical circuit depend?

What to do:

(*a*) Secure a calorimeter (a double-walled container), and a heating coil made of a high-resistance wire wound on a porcelain support. The heating element should

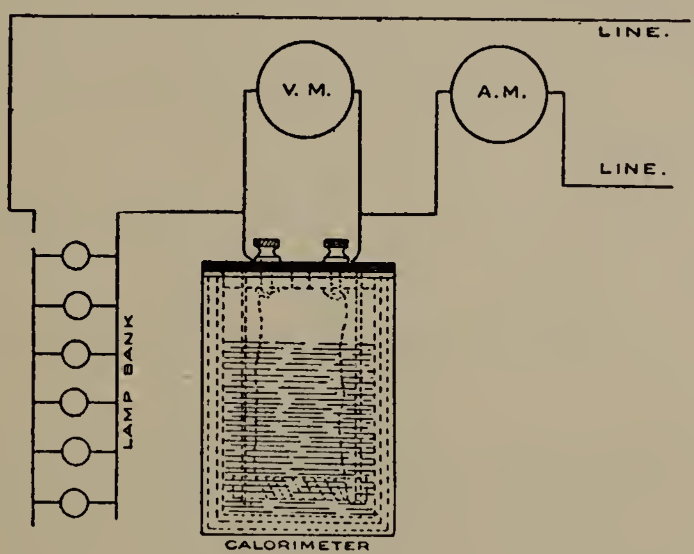


FIG. 86.

be so suspended that it is about three-fourths down into the calorimeter. The calorimeter should be provided with a tight-fitting top having an opening into which a thermometer can be inserted. It should also have some means of keeping the liquid in the calorimeter in motion.

(*b*) After having placed into the calorimeter a known amount of water (about 200 c.c.) and by means of a thermometer noted the temperature, connect the coil in series with an ammeter and source of current whose strength

can be regulated. Adjust the current to read about 3 amp. By means of a voltmeter determine the drop across the calorimeter. Allow the current to flow for 5 minutes. Keep the liquid in motion all the time and at the end of the time make note of the temperature. Shut off the current, disconnect the calorimeter and clean thoroughly; being sure that all parts are perfectly dry and polished before putting away.

(*c*) From your results find the change of temperature. Then calculate the amount of heat received by finding the number of calories of heat required to raise the calorimeter and water over this difference of temperature.

(*d*) Find the heat delivered from the formula

$H = 0.24 \times I^2R \times t$ or better $H = 0.24 \times$ watts $\times$ time in seconds. Compare this value to the one just obtained above. How many watt-hours are required to produce one calorie?

Questions.—Of what practical value is the heat produced in an electrical current?

Name some commercial articles which make use of the heat produced.

Can we have an electrical circuit in which there is no heat produced? Where does the heat generally go?

Materials Required.—Calorimeter; thermometer; graduate; voltmeter; ammeter; source of current which can be regulated (lamp bank or rheostat); balance to find weight of the calorimeter; heating coil.

EXPERIMENT 106

ELECTRICAL OPERATION COSTS

Of what value is a cost of operation test?

What to do:

(*a*) Connect different electrical devices such as a flatiron, soldering iron, disk stove, toaster, or lamp bank in series with an ammeter and a source of current. Connect a voltmeter across the terminals of the device to secure the pressure. Close the circuit and read the meters. Substitute each device in turn and record your results in tabular form. From them calculate the cost of operating for 1 hour if current sells at 4 cts. per kilowatt-hour. Calculate also the heat produced during this time. $H = 0.24 \times \text{watts} \times \text{time in seconds}$.

Device				
Volts				
Amperes				
Resistance				
Watts				
Kilowatt-hours				
Heat per minute				
Heat per hour				
Cost per hour				

(*b*) Are electrically heated devices cheaper to use than those which use other means of heating?

What advantages have the electrical devices over the others?

Name some objectionable features about them.

Materials Required.—Several commercial electrical devices, such as a disk stove, toaster, flatiron, soldering iron, lamp bank or other device; a voltmeter; and an ammeter.

EXPERIMENT 107

THERMO-ELECTRIC GENERATORS

Where are thermo-electric couples employed to great advantage in the commercial world?

What to do:

(*a*) Connect a thermo-electric generator to a source of gas and by means of a gas meter determine the input energy. To determine the output connect the electrical side of the generator in series with an ammeter and a variable resistance. To find the pressure connect a voltmeter across the terminals.

(*b*) Make four different tests, that is, regulate the gas so that it will burn with four different sizes of flame, very low, low, medium, and high. For each of the four different input values have ten different values of current output.

(*c*) Record your results in tabular form and find the efficiency in each case. Plot a curve for each input, showing the relation between the B.t.u. output and the efficiency.

One watt = 3.412 B.t.u. per hour.

One cubic foot of gas yields about 650 B.t.u.

Volts	Amperes	Watts	B.t.u.	Efficiency

The input is a constant for any one test.

(*d*) Count the number of couples in the generator.

What is the maximum voltage obtained?

What then is the voltage generated by each couple.

Where would you suggest to use the thermo-generator, or the thermo-couple?

Materials Required.—Thermo-electric generator (Gulcher's patent); gas meter; voltmeter; ammeter; and a variable resistance.

EXPERIMENT 108

PYROMETERS

Where would you suggest to use pyrometers?

What to do:

(*a*) A pyrometer is a thermo-electric couple used to indicate rather high temperatures by means of the current generated at the junction of the two elements. Make such a couple by twisting about an inch of the ends of a piece of German silver wire and a copper or iron wire very firmly together. The ends might be fused together in a good Bunsen burner. This couple will answer very nicely for moderately high temperatures. Connect the free ends of the wires to a very delicate lecture-room galvanometer or miliammeter. Slip the couple through an asbestos tube, allowing the twisted end to protrude, or rap a piece of asbestos paper around the wires so that they may be handled without burning the fingers.

(*b*) To calibrate the couple which you have just constructed heat some water up to the boiling point. Place the couple and a thermometer side by side in the water, being careful that neither comes into contact with the side or bottom of the vessel. Make note of the thermometer reading and at the same time read the meter deflection. This meter reading corresponds to the temperature of the water. What is it? Since the meter deflections are always proportional to the current sent through the instrument and since the current developed depends upon the temperature, it follows that each division may be made

to correspond to a definite change in temperature. For example, suppose that the meter deflects ten divisions when the thermometer reads 100°C. Then one division would represent one-tenth of that value or 10°C.

(*c*) Having thus calibrated your couple or, better, pyrometer, determine by means of it the temperature of various spots or parts of an iron plate which is being heated over a Bunsen flame. Try also the various parts of a vessel of some liquid which is being heated (a sauce pan of water will do).

Questions.—What advantages are there in determining temperatures by means of this method? How could this method be applied to a cold-storage plant? How to a heating system?

Materials Required.—Galvanometer or miliammeter; piece of German silver wire; piece of iron wire (fine); piece of asbestos paper or tube; beaker of water; Bunsen burner; and a small plate of iron or other metal.

EXPERIMENT 109

THE DYNAMO

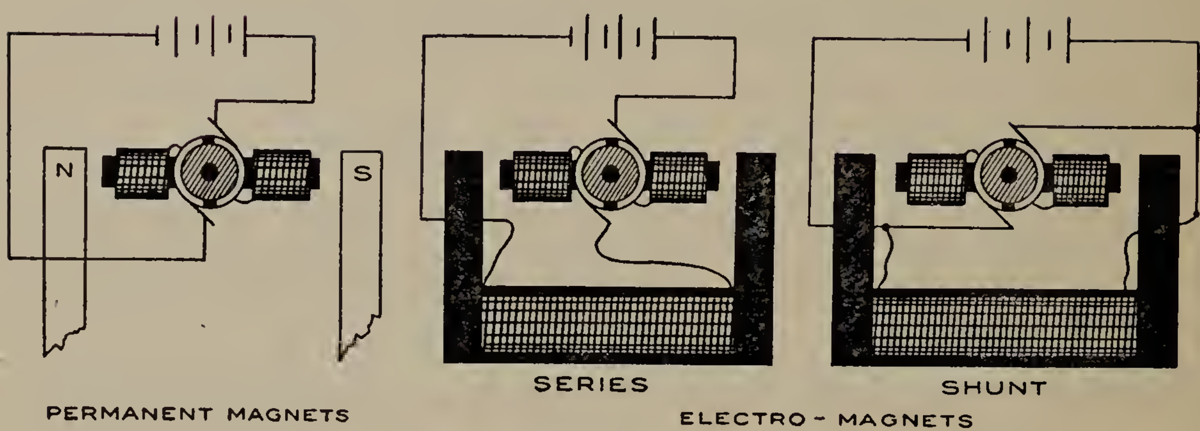


FIG. 87.

How can you distinguish a motor from a generator?

What to do:

(*a*) The essential parts of a dynamo are few and their operation is simple if "Faradays' Laws of Electro-magnetic Induction" are kept in mind. The most important parts are (1) the Fields, the part which furnishes the magnetic lines of force; (2) the Armature, generally the rotating element and the one in which a current is generated; or which if supplied with current produces rotation; (3) the Commutator (in alternating-current machines the slip rings), the part at which current is collected or by means of which the current is sent into the armature; (4) the brushes which slide on the commutator or rings and provide a method of taking off the current or putting it into the armature.

(*b*) With permanent magnets—Secure a "St. Louis Motor" which has permanent magnets. Identify the

parts mentioned above and note their construction. Remove the magnets from their supports. Is the commutator a continuous piece of metal? Describe its construction.

(*c*) See that the brushes are resting on the commutator lightly but so that contact is good. Connect a dry cell in series with a push botton and the armature circuit. Close the circuit and by means of a pocket compass investigate the polarity of the poles of the armature during a complete revolution. Is the polarity of any pole the same throughout the entire revolution? If not, where does it change and why? If the bar magnets were in place, what would be the condition existing between them and the armature poles?

(*d*) Replace the bar magnets so that you have a north and a south pole facing the armature. Do these magnets touch the armature? The space between the magnets and the armature is called the "air gap". With the magnets thus in place, again close the battery circuit. What is the result? Why is rotation produced? What is the direction? Reverse the magnets so that you will have a north pole where you had a south pole. Again close the battery circuit and note any change that might take place. While the motor is running increase the air gap slightly at first and then make it about 5 in. What is the result? What are your conclusions concerning the magnetic field?

(*e*) Bring the magnets back to their original position slowly. What is the result? Reverse the battery connections, thus reversing the current through the armature. What happens?

(*f*) Now connect a galvanometer in circuit in place of the battery. Rotate the armature by hand, first in one direction and then in the other and at different speeds.

What is the result? Separate the magnets slightly and try again. What laws are involved in this operation? State them.

(*g*) Replace the galvanometer by a battery and the permanent magnets by an electromagnet. Connect up as a "Series" motor (see Fig. 87)—that is, so that the field coil and the armature circuit are in series with each other. Close the circuit, making note of the direction and speed of rotation. Reverse the field connection. What is the result? Reverse the battery connection. What is the result?

(*h*) Connect up as a "Shunt" motor (see Fig. 87)—that is, connect the field circuit in parallel with the armature circuit. Close the battery circuit and note the direction of rotation and also the speed. Is the speed as great as before or greater? Why? Reverse the field connections. What is the effect? Reverse the battery connections. Result? How do you account for this action?

Questions.—How can the direction of rotation of a series motor be changed? How can a shunt motor be reversed? Where would you suggest to use series motors and where shunt motors?

Materials Required.—A St. Louis motor; galvanometer; pocket compass; one or two dry cells; and a push button.

NOTE.—Better results will be secured if brushes of *stiff* German silver wire are used in place of the soft copper ones which are generally furnished with the motors.

EXPERIMENT 110

MOTOR POWER TEST

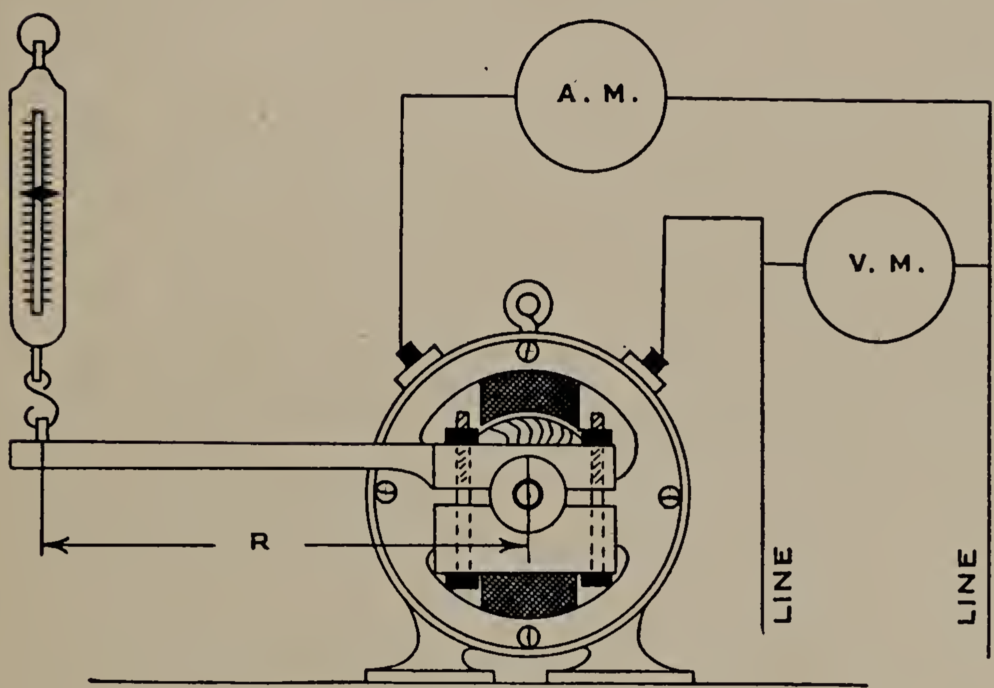


FIG. 88.

What is the real value of a power test?

What to do:

(*a*) Connect the motor to be tested in series with an ammeter and a source of current. Determine the volts drop across the motor by means of a voltmeter. Fasten to the motor a prony or strap brake and then determine the following. The radius of pull if the prony brake is used will be from the center of the pulley to the point of application of the load, distance *R* in sketch. If strap brake is used, it will be the radius of the pulley. The radius should be read in feet. The pull should be determined in pounds. If the strap brake is used, this will be the difference between the two scale readings. Calculate

the power developed and the efficiency at 50-100-150 per cent. full load (150 per cent. full load = 50 per cent. overload) and record your results in the following table:

Input	50 per cent.	100 per cent.	150 per cent.
Volts			
Amperes			
Watts			
Horsepower			
Output			
Radius of pull in feet			
Speed in r.p.m.			
Net pull in pounds			
Foot-pounds output per minute			
Horsepower output			
Efficiency = output ÷ input.			

To find the horsepower output use the following formula:

$$\text{Hp.} = \frac{2\pi R \times \text{r.p.m.} \times \text{pull}}{33{,}000}$$

A good efficiency for a motor under full load should be between 80 and 90 per cent. Does your machine have this value? How do you account for any difference. Why cannot a motor have an efficiency of 100 per cent.?

Materials Required.—A motor (either shunt or series-wound); strap or prony brake; a spring balance; speed counter; a voltmeter; and an ammeter.

EXPERIMENT 111

ARC-LAMP EFFICIENCY TEST

Why are arc lamps used for street lighting and not used in private homes?

What to do:

(*a*) Examine any standard arc lamp carefully. Make note of the three main parts, the arc, the resistance or regulating coils, and the magnet coils. Make a sketch of the lamp showing all connections. Remove the carbons from the lamp and mark them so that you can distinguish one from the other. Weigh them very carefully and then replace them in the lamp.

(*b*) Connect the lamp in series with an ammeter and a source of current. Now with a voltmeter determine the fall of potential across the various parts. Allow the lamp to burn for about half an hour. Then remove the carbons and weigh them as before. Calculate the loss of weight and from this estimate the life of the carbons in hours.

(*c*) Record your results in tabular form and from them calculate the electrical efficiency of the lamp. Find also the cost of operation per hour at 4 cts. per kilowatt-hour. Estimate the candlepower of the lamp assuming 1 watt per candle in the arc.

(*d*) What is the object of the dash-pot?

Why have more regulating coils than are actually used?

What keeps the carbons a definite distance apart?

Can this distance be regulated? How?

Why use cored carbons in some lamps and solid ones in others?

Why are some arc lamps of the enclosed type?

Test number			
Terminal volts			
Line current			
Arc volts			
Arc resistance			
Regulating-coil volts			
Regulating-coil resistance			
Magnet-coil volts			
Magnet-coil resistance			
Total watts			
Arc watts			
Efficiency			

Materials Required.—Beam balance to weigh carbons; arc lamp; voltmeter; ammeter; and source of current.

EXPERIMENT 112

THE MERCURY-ARC RECTIFIER

Where and for what purpose is the mercury-arc rectifier used?

What to do:

(*a*) Connect a mercury-arc rectifier in series with a direct-current ammeter and a set of storage cells which are so arranged that any number of them can be connected in circuit at will. Arrange a direct-current voltmeter so that the fall of potential across those cells in circuit can be obtained. Connect an indicating wattmeter in the supply circuit so that the power delivered to the rectifier can be measured.

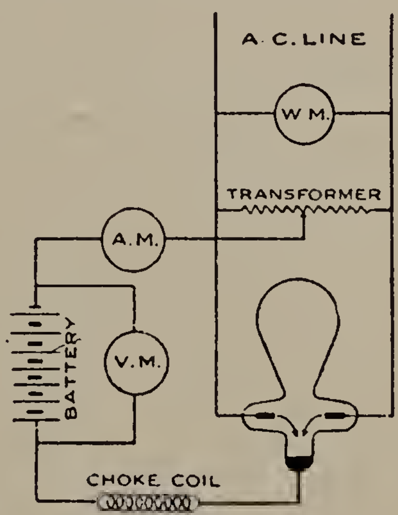


FIG. 89.

(*b*) Adjust the rectifier so that it takes the lowest possible load at the lowest possible pressure. Increase the load, step by step, until the maximum rated value of output of the machine is reached.

(*c*) Record your results in tabular form and from them calculate the efficiency for each output. Plot a curve for the machine showing the relation between current output and efficiency. From this determine at what output the efficiency is a maximum.

Test	Output			Input	Efficiency
	Volts	Amperes	Watts	Watts	

(*d*) Where are mercury-arc rectifiers used to great advantage?

Why are they used in preference to dynamos?

What is a good efficiency for such a machine?

What limits their capacity?

What kind of a current does the rectifier deliver?

Materials Required.—Mercury-arc rectifier; indicating wattmeter (alternating current); voltmeter (direct current); ammeter (direct current); and a set of storage cells.

Introduction to Alternating-current Experiments.—The introduction of alternating-current experiments in a laboratory manual for high-school physics being a proceeding somewhat out of the ordinary, the authors feel that a statement by way of explanation is not out of place. We are so firmly convinced of the importance of alternating-current experiments in physics that we feel sure that in a few years the fact that any apology for the introduction of such experiments in a physics manual was offered will be regarded as an anomaly.

Our apology is, first, the importance of the subject and, second, our conviction that high-school pupils can grasp the principles of alternating currents as readily as those of direct currents. By far the greater number of practical applications of electricity are in the field of alternating currents.

The time for these experiments may be arranged for in a number of ways. The following are suggested: (1) A boys' class in the one-year physics course giving more than the usual time to electricity. (2) A third semester of physics devoted to electricity. (3) Permitting the more rapid workers in the regular physics class to work some of the alternating-current experiments as extra experiments.

The required apparatus is simple. With a Gramme ring coil (described in connection with the experiment on the induction motor), a bell-ringing transformer, five 2-M.F. condensers, an alternating-current voltmeter, and an alternating-current ammeter most of the experiments can be performed. The "Simplified Transformer Set" designed by one of the authors of this manual materially increases the range of the experiments. It is assumed that the laboratory is provided with a 110-volt alternating-current lighting circuit. If the laboratory is provided

with direct current only a motor-generator is required. The cost of equipping the laboratory with one complete outfit for alternating-current experiments need not exceed $85. If the Gramme ring coil is made in the laboratory, the cost can be reduced to $65.

Following is a list of apparatus needed. Apparatus that is for alternating-current work only is starred. The apparatus not starred is used also for direct-current experiments.

*Gramme ring coil. (For the experiment on phase transformation, two coils are needed.)

*Simplified transformer set.

* Bell-ringing transformer.

* Five 2-M.F. condensers.

* One 1-M.F. condenser. (Use telephone condensers mounted and provided with binding posts.)

* Alternating-current voltmeter. (A double-range instrument; 150 and 15 volts is recommended.)

* Alternating-current ammeter, reading to 10 amp.

Lamp bank.

Slide-wire bridge.

Small motor or dynamo.

Mill-voltmeter, direct-current, with zero-center scale.

Electromagnets.

Four lamp sockets with porcelain base.

Small hand magneto.

Two-pole knife switch.

Variable resistance.

Watt-hour meter. (Use either a direct-current or an alternating-current meter. A direct-current meter works equally well for alternating-current. The meter can be borrowed from the local electric light company.)

Indicating wattmeter. (This can be dispensed with and the watt-hour meter used in its stead.)

EXPERIMENT 113

MAGNETIZING AND DEMAGNETIZING STEEL

Which kind of current, alternating or direct, is used in magnetizing steel and which can be used for demagnetizing?

What to do:

(*a*) Connect to a direct-current circuit two coils in series, each coil having a soft iron core. Use a lamp bank in series with the coils if the resistance of the coils is not high enough for your line voltage. Test the polarity of the coils with a small compass and make sure that the ends of the coils nearest together are of opposite polarity. Test a small bar of steel with iron fillings to make sure that it is not magnetized, then place the bar between the coils the ends touching the soft iron cores. Let the steel bar remain in this position from 3 to 5 minutes while a current is flowing in the coils. Again test the steel with iron filings. What is the result?

(*b*) Connect the same coils to an alternating-current circuit. Place the steel bar used in (*a*) in the same position as before and after 3 minutes test it with iron filings.

Explain the difference between the action of magnetic fields of alternating and direct current on the steel.

Fill out the blanks in the following statements:

A bar of steel may be magnetized by means of ——— current.

A magnet may be demagnetized by means of ——— current.

If you had a magnetized knife how could you demagnetize it?

Materials Required.—Two electromagnet coils with removable cores; small bar of steel; lamp bank; iron filings; pocket compass.

EXPERIMENT 114

PRINCIPLE OF THE TRANSFORMER

What is a transformer? Why are transformers used?

What to do:

(*a*) Connect the primary coil (Fig. 90) to the 110-volt alternating-current circuit. Connect an incandescent lamp of the proper voltage to the secondary coil. Move

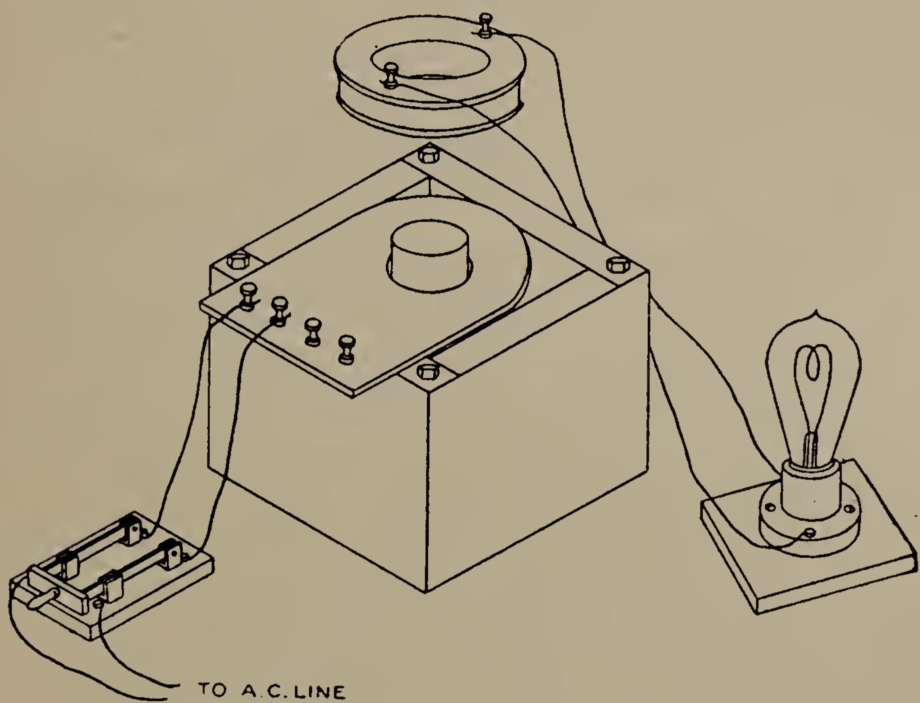


FIG. 90.

the secondary coil to and from the primary and notice that the lamp lights and varies in brightness according to its distance from the primary. Since the current in the primary is alternating, its magnetic field is constantly changing. Hence the magnetic lines of force produced by the current in the primary coil move to and fro across the secondary coil. These magnetic lines of force moving

across the secondary induce a current in the secondary coil and this current lights the lamp. Note the greatest distance from the primary at which you can hold the secondary and see any effect on the lamp.

(*b*) To discover if there is any effect on the secondary at a great distance, connect a telephone receiver to the secondary in place of the lamp and note the greatest distance from the primary at which you can hold the secondary and hear a buzzing in the receiver. What would be the effect on a telephone line of an alternating-current power line placed near it?

(*c*) In the preceding tests there is great loss of power because only a small part of the magnetic field of the primary can act on the secondary. In a transformer the primary and secondary are wound on the same iron core and the two windings are enclosed in an iron housing which permits little or no magnetic leakage, that is, practically all of the magnetic field of the primary acts on the secondary. Put the coil and core into the housing, or use a bell-ringing transformer and connect the high-voltage winding (the winding with the greater number of turns) to the 110-volt alternating-current circuit. With an alternating-current voltmeter find the voltage at the terminals of each winding. This is a step-down transformer.

(*d*) Now connect the low-voltage winding to the 110-volt circuit.

Caution.—This cannot be done if a bell-ringing transformer be used.

If the secondary has about twice as many turns as the primary, connect two 110-volt lamps in series to the terminals of the secondary. What voltage, approximately, is there at the terminals of the secondary?

Caution.—Do not test this voltage with a voltmeter reading only 120 volts or less. The lamp test is sufficient

to indicate approximate voltages. Voltage across terminals of each lamp may be taken and results added.

This is a step-up transformer. What is the difference between a step-up and a step-down transformer? Why can you not use a transformer on a direct-current circuit?

Materials Required.—Simplified Transformer Set; alternating-current voltmeter reading 120 volts; automobile headlight lamp, 6-volt, to be connected to the auxiliary coil; two 110-volt lamps with sockets or a lamp bank arranged for series connection; telephone receiver.

EXPERIMENT 115

SELF-INDUCTION IN A DIRECT-CURRENT CIRCUIT

Introductory.—This experiment illustrates the principle of a type of spark coil, frequently used for gasolene engines, consisting essentially of a single coil. Such a coil is operated by a direct current and has no vibrating interrupter.

What to do:

(*a*) Set up the apparatus according to Fig. 91. Use a coil having 500 or more turns of wire and an iron core,

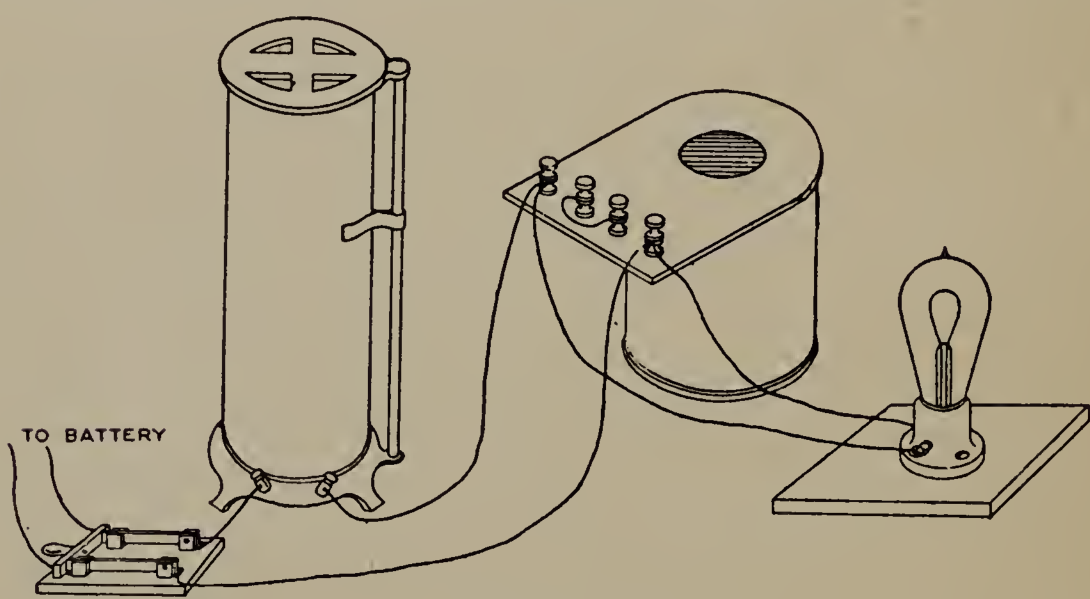


FIG. 91.

a storage battery of 6 volts or more, and an incandescent lamp suited to the voltage of the battery. Insert enough resistance in the lamp circuit to dim the lamp to a dull red.

(*b*) Make and break the circuit with the switch. The flashing of the lamp when the battery circuit is broken is

due to self-induction. The action of the magnetic field causes the current to continue to flow after the battery circuit is broken.

(*c*) The spark coil operates on the same principle. The spark gap takes the place of the lamp. When the battery circuit is broken the impulse due to self-induction

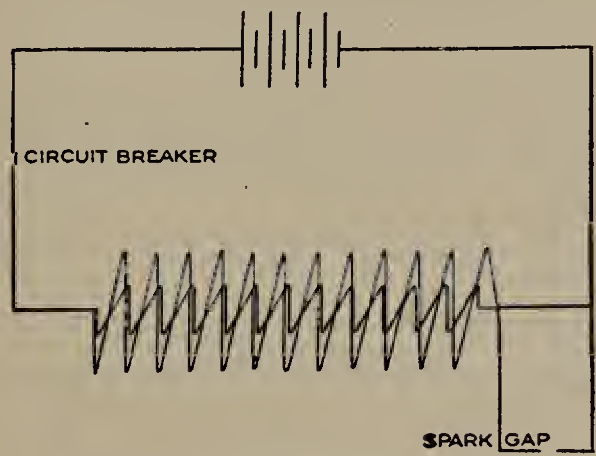


FIG. 92.

causes a spark to pass across the gap. If such a coil is at hand make the proper connections and observe its operation (see Fig. 92).

Materials Required.—Coil; switch; contact key; storage battery; incandescent lamp of proper voltage. If a 6-volt battery is used, a 6-volt bulb such as those used in automobile headlights is suitable.

EXPERIMENT 116

THE CHOKE COIL

A coil in series with a lamp in an alternating-current circuit dims the lamp but produces no such effect in a direct-current circuit. Why?

What to do:

(*a*) Connect the choke coil in series with an incandescent lamp to the alternating-current lighting circuit as

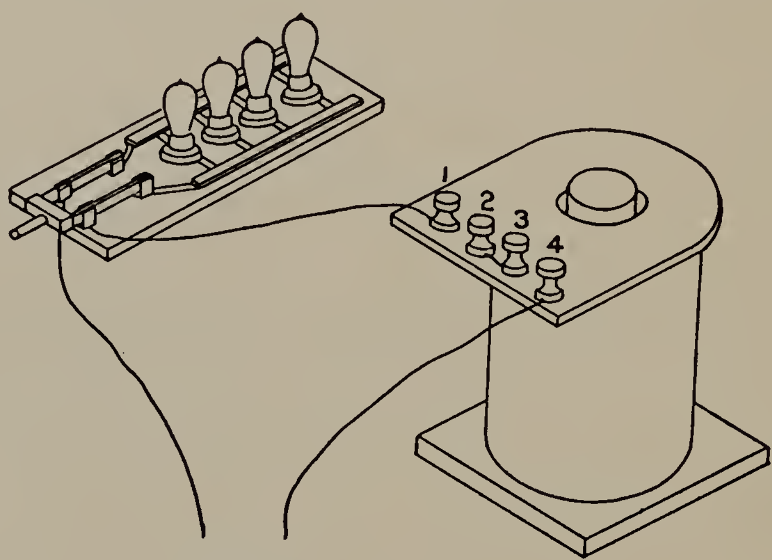


FIG. 93.

shown in Fig. 93. Insert the core into the coil and note the change in the brightness of the lamps. A coil can be used in this way as a dimmer.

Consider the magnetic field of the coil. Since the current is alternating, the field is constantly changing and the lines of force are moving back and forth across the turns of the coil. This magnetic action induces an electromotive force in the coil which on the whole opposes

the electromotive force of the line, thereby reducing the strength of the current which flows through the lamp.

(*b*) Connect the lamp and coil in the same way to a direct-current circuit. Try the effect of inserting the core in the coil. How does the magnetic field of a coil connected to a direct-current circuit differ from that of one connected to an alternating-current circuit? Why is the lamp not dimmed when direct current is used?

Materials Required.—Lamp bank; coil with removable soft iron core (coil should have at least 300 turns); alternating- and direct-current circuits of 110 volts.

EXPERIMENT 117

MAGNETIC ACTION OF PRIMARY AND SECONDARY COILS

Is the magnetic action between primary and secondary coils attraction or repulsion?

What to do:

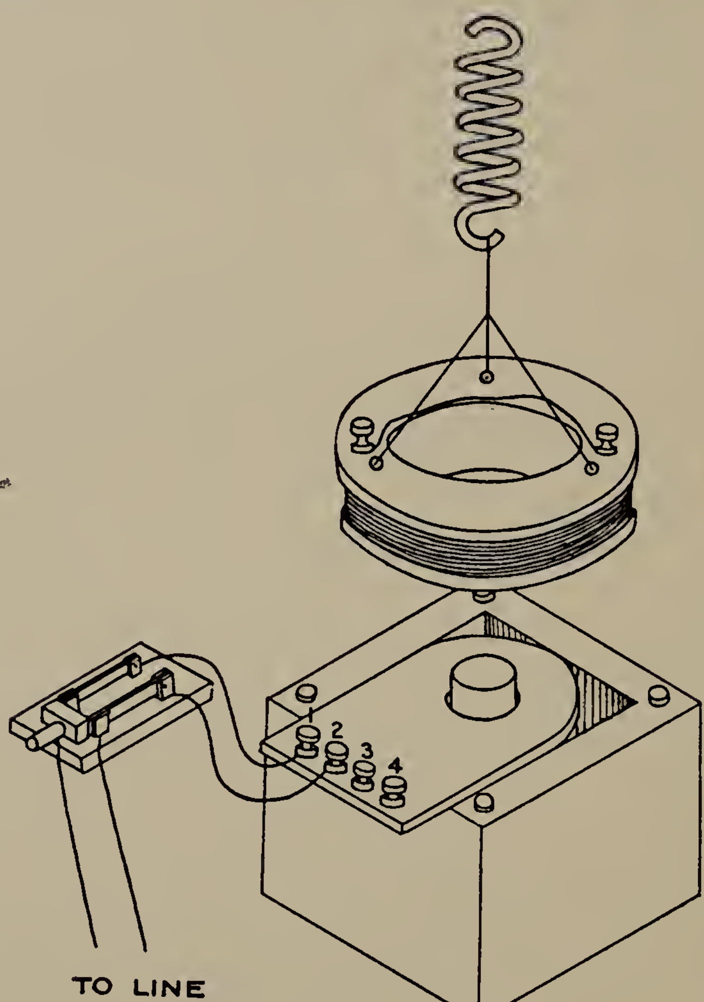


FIG. 94.

(*a*) Set up primary and secondary coils as shown in Fig. 94. The secondary may be suspended by a spring or a rubber band.

(*b*) Close the circuit of the primary and note the effect

on the secondary. Note the effect when the primary circuit is broken.

Caution.—The primary circuit must be kept closed only a few seconds at a time. If closed for a longer time the coil may become overheated.

Repeat several times to make sure of the result. In which case do you observe attraction? In which case repulsion? Look up Lenz's law in your text-book. Can you see how this experiment illustrates Lenz's law?

Materials Required.—Simplified Transformer Set; switch; support for secondary coil.

EXPERIMENT 118

EFFECT OF A CONDENSER

What is the effect of a condenser when connected in series with an incandescent lamp in an alternating-current circuit? Does it have the same effect in a direct-current circuit?

What to do:

(*a*) Connect in parallel five condensers, each having a capacity of 2 microfarads. This forms a condenser

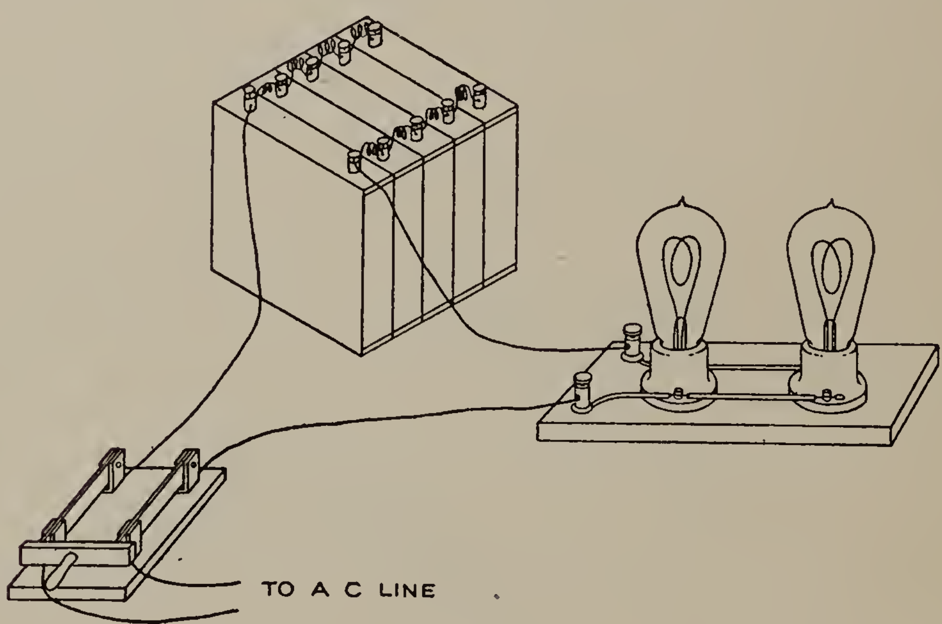


FIG. 95.

whose capacity is 10 microfarads. A farad is the capacity of a condenser in which a current of 1 amp. is produced when the voltage at its terminals changes at the rate of 1 volt per second. A microfarad is one-millionth of a farad. Connect the 10-M.F. condenser in series with a lamp bank and a 110-volt alternating-current circuit (Fig. 95). Turn on one or two lamps in the lamp bank. The

lamps will light. Remember that there is no electrical connection between the two sets of plates of the condenser. The lamps are, therefore, lighting on an open circuit. Why do they light?

(*b*) Connect the lamps and the condenser in the same way to a 110-volt direct-current circuit. Explain the result.

(*c*) Connect the lamps again to the alternating-current circuit. Disconnect the five condensers one at a time. The lamps become dim as the condensers are removed. This shows that the less the capacity of the condenser the greater is its reactance or opposition to the current.

(*d*) If a transformer of sufficiently high voltage for a spark gap is at hand, connect its primary to the line and adjust the spark gap of the secondary to give a good spark. Open the circuit and connect the 10-M.F. condenser as a shunt across the spark gap. Close the circuit and note the effect of the condenser on the spark.

Materials Required.—Five 2-M.F. condensers; wire; lamp bank; transformer with spark gap in secondary; alternating current and direct-current 110-volt circuits.

EXPERIMENT 119

CONDENSER AND CHOKE COIL

Introductory Discussion.—A choke coil causes the current to lag, that is, there is a difference of phase between current and voltage, the current falling behind the voltage. A condenser, on the other hand, causes the current to

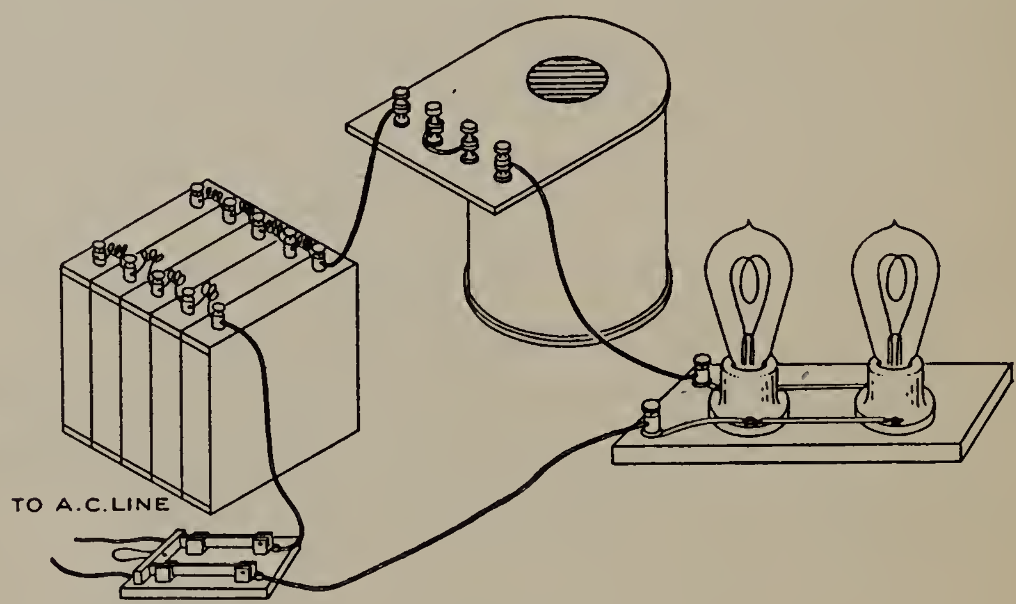


FIG. 96.

lead, that is, the current is ahead of the voltage in phase. The object of this experiment is to show that lag and lead may be made to balance each other. This condition is called resonance.

What to do:

(*a*) Connect the lamp bank, the choke coil with the core removed, and a 10-M.F. condenser all in series as in (Fig. 96.) Insert two 50-watt lamps in the lamp bank. The lamps are dimmed by the reactance of the condenser. Now insert the core into the coil; and the coil and core, part

way into the iron frame. When the coil and core are in a certain position in the frame, the lamps glow brightly. This position can be found by trial. The reactance of the condenser is then balanced by the reactance of the coil. The two reactances are equal and produce opposite effects. Hence the effect of one is neutralized by that of the other.

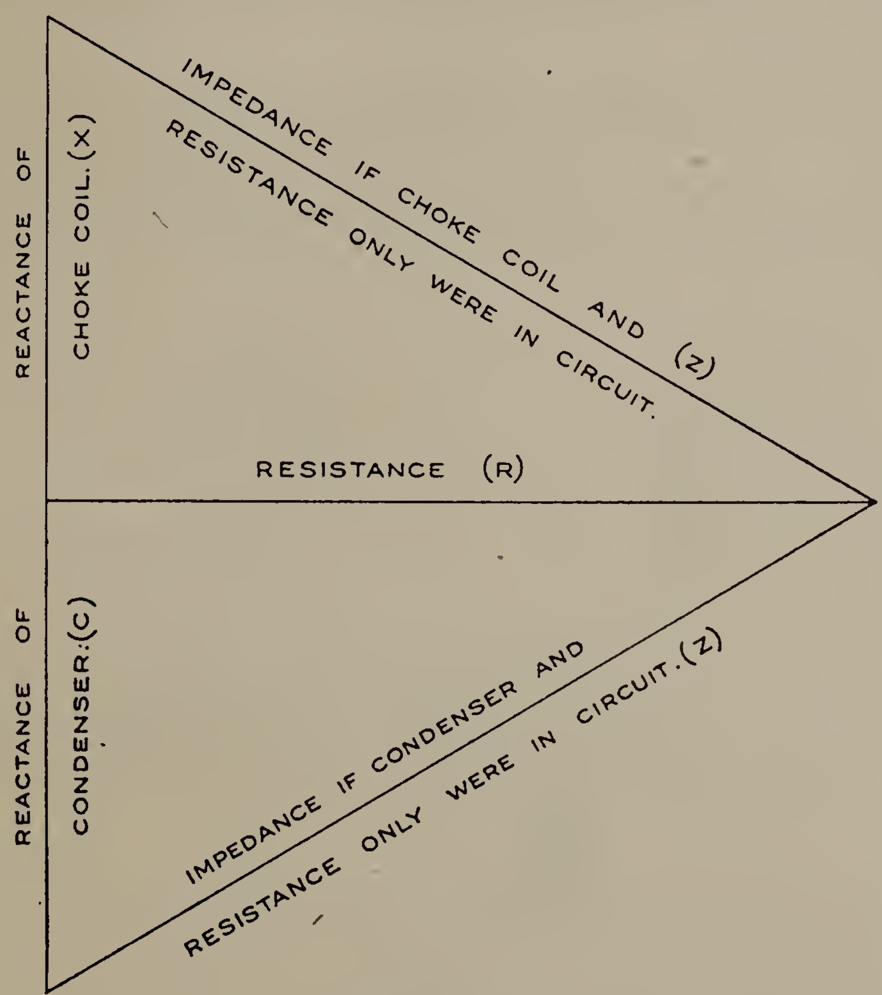


FIG. 97.

Fig. 97 illustrates the relation between the two reactances.

Materials Required.—Coil, core, and frame of the Simplified Transformer Set to be used as a choke coil; a 10-M.F. condenser which can be made by connecting five 2-M.F. condensers in multiple; a lamp bank.

EXPERIMENT 120

COMPARING THE CAPACITIES OF TWO CONDENSERS

What to do:

(*a*) Set up a Wheatstone bridge and make connection as shown in Fig. 98. Use a 110-volt alternating-current circuit connecting a 40- or 60-watt lamp in series with the bridge.

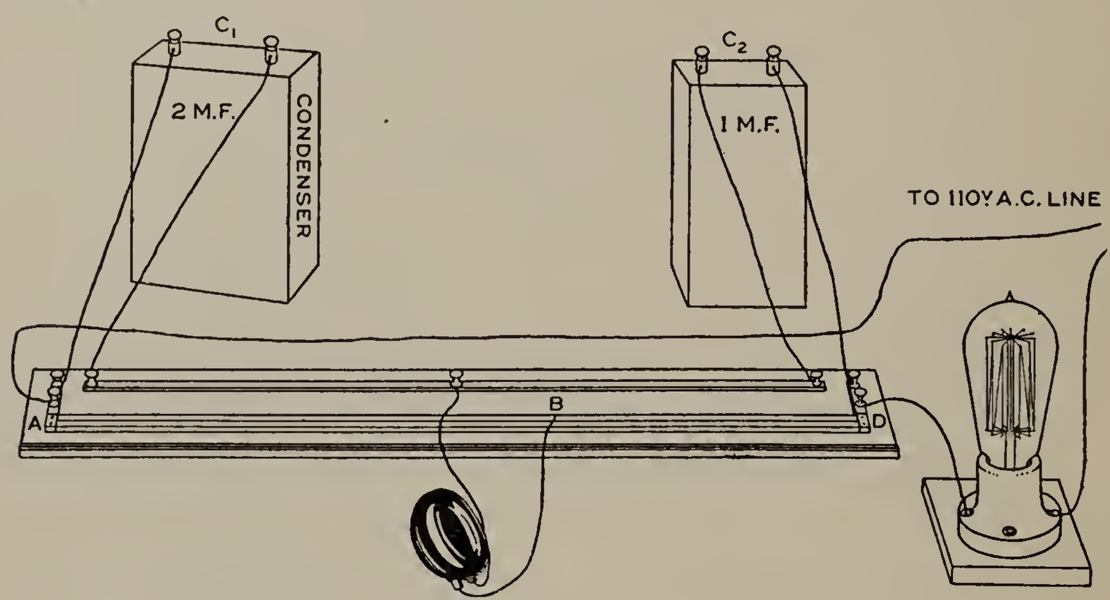


FIG. 98.

(*b*) Touch the wire which is connected to the receiver at different points on the slide wire until you find a point where contact produces no buzzing in the receiver. If the buzzing does not quite disappear but becomes faint at some point reduce the strength of current by putting in a 25-watt lamp in place of the one first used.

The capacities are inversely proportional to the corresponding lengths of the slide wire. The proportion is

$$\frac{C_1}{C_2} = \frac{BD}{AB}.$$

To understand this proportion recall experiment 118 where it was shown that the greater the capacity of a condenser the stronger is the current which it permits to flow. In other words, the reactance, which is the opposition to flow of current, is inversely proportional to capacity. Of the two condensers, C_1 and C_2, the one which has greater capacity offers less opposition to the current, while of the two resistances AB and BD, the greater resistance offers greater opposition to the current. It follows that when two condensers are in series, as C_1 and C_2, the voltage drops are proportional to the reciprocals of the capacities while the voltage drops across two resistances in series, as AB and BD, are directly proportional to the resistances. Hence the proportion given above.

Compare this proportion with that used in measuring resistances by the Wheatstone bridge method.

If one of the condensers has a capacity of known value the capacity of the other may be computed by means of the proportion just given.

(*c*) Take three condensers of equal capacity. Connect two of them in series as the unknown capacity and the single condenser as the known capacity and find how the capacity of the two condensers compares with that of one.

(*d*) Connect two condensers in parallel and find how their capacity when thus connected compares with that of one condenser.

Materials Required.—Slide-wire bridge; three condensers of equal capacity; a fourth condenser which may differ from the other three and may have a known capacity; telephone receiver; lamp bank; wires for connections.

EXPERIMENT 121

INSTANTANEOUS VOLTAGES

How does the electromotive force change during a revolution of the armature of a dynamo?

What to do:

(*a*) Connect the brushes of a dynamo or motor to a mil-voltmeter. Connect the field coils to a source of current, either a storage battery or 110-volt direct-current circuit. If the 110-volt circuit is used, a lamp bank or other resistance must be connected in series with the field coils. The field coils should be connected to the line through a two-pole knife switch. The armature is not to be turned except as directed.

Caution.—To prevent injuring the mil-voltmeter make the test first with a voltmeter reading to 120 volts. If the pointer of the voltmeter barely moves, it is safe to use the mil-voltmeter. A weak current should be used at first, not more than ½ amp., and tests made for a complete revolution before using a stronger current. Be sure that the armature is at rest when the test is made.

The induced voltage indicated by the mil-voltmeter is caused by breaking the circuit of the field coils, thus causing magnetic lines of force to move across the armature as the magnetic field is destroyed. The voltages obtained in this manner have the same relation to each other as the voltages generated during a revolution of the armature; but it is to be noted that there is a difference of phase of 90° between the voltages obtained in this experiment and

those that occur during a revolution of the armature. The reason is as follows: When the armature rotates, the maximum voltage occurs when the armature winding is parallel to the lines of force for the coil is then cutting the greatest number of lines of force. In this experiment, however, a voltage near zero is obtained when the coil is parallel to the lines of force because in this position the fewest lines of force thread through the coil; hence on breaking the circuit only a slight e.m.f. is generated. If the brushes bear on slip rings, connect the wires to the brushes. If the dynamo has a drum armature, connection must be made throughout the experiment with the same two commutator segments. This can be done by holding the wires in contact with the commutator segments.

(*b*) Close the switch and, after the pointer of the mil-voltmeter has returned to zero, open the switch making as sudden a break as possible. Get the voltage as indicated by the mil-voltmeter at the instant of breaking the circuit. Now turn the armature through 15° and make another test. Repeat the tests, turning the armature 15° each time until you have tests for one complete revolution.

Can you answer the question asked at the beginning of the experiment?

(*c*) Construct a graph, letting the abscissas represent the angles through which the armature was turned and the ordinates represent the voltages measured in mil-volts. This is the voltage graph for the dynamo you are testing. If the dynamo has a two-pole field, the graph represents one cycle and shows the actual voltages developed in the armature.

(*d*) These tests may be repeated using a stronger current in the field coils if the mil-voltmeter will stand it.

Questions.—1. What is meant by a cycle?

2. Suppose the armature of your dynamo were to make

3,600 revolutions per minute, how many cycles per second would be produced?

3. Are there any irregularities in your graph? If so, they may be accounted for by the magnetic field not being uniform.

Materials Required.—A small dynamo or motor having a shuttle or drum armature and the connections so arranged that the armature and the field coils may be connected separately. Either an alternating-current or a direct-current machine may be used.

A storage battery or a lamp bank.

A two-pole, single-throw knife switch.

A mil-voltmeter, one with zero-center scale preferred. If the zero is at the end of the scale and the dynamo has slip rings, it is necessary to reverse the connections at the point where the voltage becomes zero.

A pointer may be attached to the end of the armature shaft and a circular scale mounted so as to indicate degrees of rotation. Great accuracy is not required.

EXPERIMENT 122

VOLTAGE DROP IN A DIRECT-CURRENT CIRCUIT

If two resistances, one being twice as great as the other, are connected in series, how does the voltage drop across one resistance compare with the voltage drop across the other? In general, what is the relation between voltage drop and resistance in a series circuit?

What to do:

Connect in series to a 110-volt circuit, four incandescent lamps that are of the same kind and rated at the same number of watts. With a voltmeter take the voltage drop across the terminals of the first lamp, then across the second and third taken together. How does the voltage drop across one lamp compare with the drop across two lamps? How does the resistance of one lamp compare with the resistance of two lamps in series?

In the same way compare one lamp and three lamps. Answer the questions asked at the beginning of the experiment.

Materials Required.—Lamp bank arranged for series connection or four lamp sockets to be connected in series; four incandescent lamps of equal rating; voltmeter.

EXPERIMENT 123

VOLTAGE DROP IN AN ALTERNATING-CURRENT CIRCUIT

Does voltage drop in an alternating-current circuit follow the same laws as in a direct-current circuit (see experiment 122)?

What to do:

(*a*) Connect a choke coil and lamp bank in series to an alternating-current circuit. Take the total voltage drop across coil and lamp bank (terminals *A* and *C*, Fig. 99). Call this V_1. Take the drop across the terminals of the

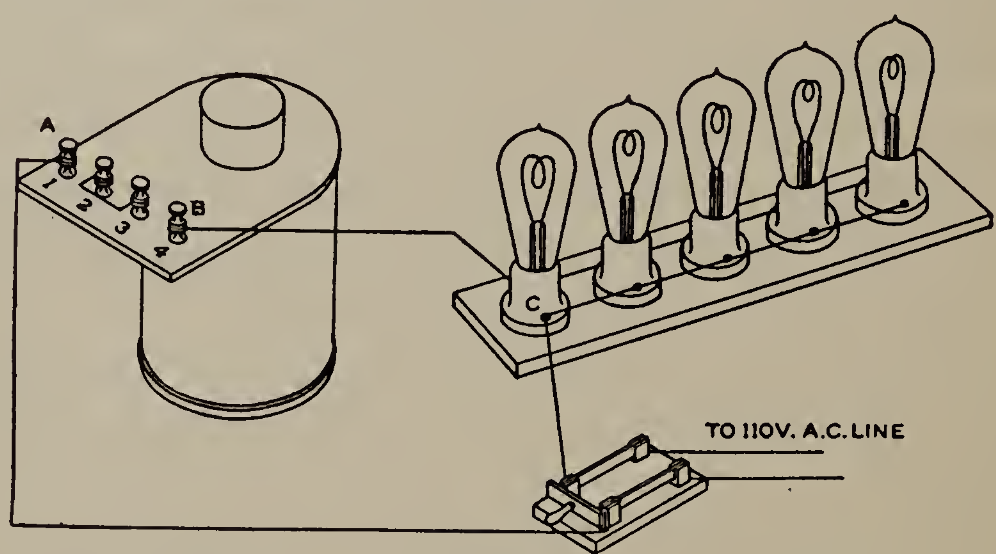


Fig. 99.

coil (*A* and *B*) and call this V_2. Take the drop across the lamp bank (*B* and *C*) and call this V_3. The total voltage drop will probably be less than the sum of the drop across the coil and the drop across the lamp bank. If the choke coil had no resistance and the lamps no reactance, that is no self-induction, the following equation would be true

$$V_1^2 = V_2^2 + V_3^2.$$

This condition is nearly realized for the resistance of the coil is very small compared with its reactance and the lamps have practically no reactance. Substitute the results of your test in the equation just given and see how nearly it is true for the circuit you are testing.

(*b*) V_1 is the voltage drop across the impedance of the circuit, V_2 across the reactance, and V_3 across the resistance. Write an equation substituting impedance, reactance, and resistance for their respective voltage drops in the above equation.

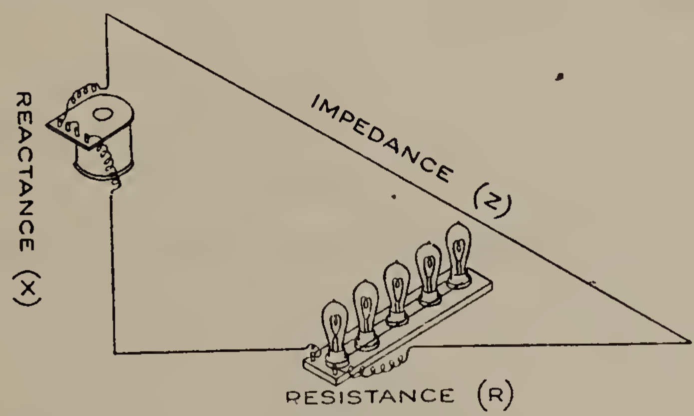


FIG. 100

In an alternating-current circuit Ohm's law holds true, if we substitute impedance for resistance. Write the equation for Ohm's law as applied to an alternating-current circuit. Answer the question asked at the beginning of the experiment.

Material Required.—Choke coil (coil and core of Simplified Transformer Set may be used); lamp bank, alternating-current voltmeter.

EXPERIMENT 124

THE ALTERNATING-CURRENT AMMETER

Can a movable-coil type direct-current ammeter be used for measuring alternating currents? If not, why not, and how does an alternating-current ammeter differ from a direct-current ammeter?

What to do:

Connect the coil of the transformer set in series with a lamp bank and suspend the iron rod from a support by means of a spring so that it is just ready to enter the coil. Hold a meter stick upright close to the rod. Turn on one lamp and note the distance the rod is pulled into the coil. Turn on two lamps and note the distance. Continue adding more lamps and measuring the distance the rod moves until all the lamps are on. How could you use this device to measure amperes in an alternating-current circuit?

In an alternating-current ammeter the armature is of soft iron like the rod in the experiment. The armature as it is pulled into the coil turns a pointer which moves over a scale indicating the number of amperes. Of what does the moving part of a direct-current ammeter consist? Answer the questions asked at the beginning of the experiment.

Materials Required.—Coil; iron rod; and spring of Simplified Transformer Set; iron ring support; lamp bank.

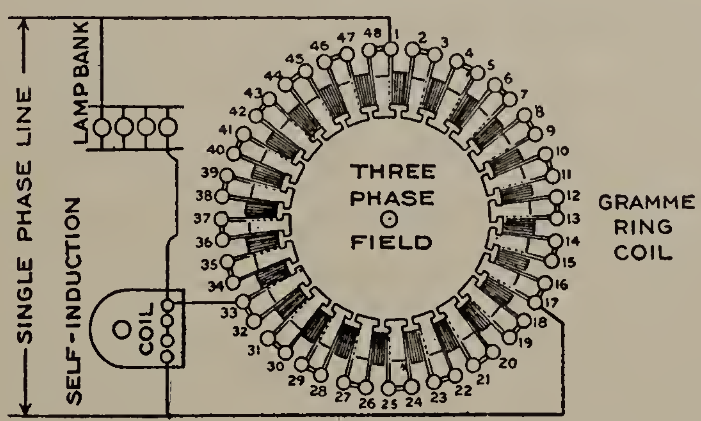
EXPERIMENT 125

THE INDUCTION MOTOR

Introductory Discussion.—There is no electrical connection between the armature (usually called the rotor) of an induction motor and the external circuit. In other words, the rotor circuit is a closed circuit. What causes the rotation? How can such a motor be made to run on a common single-phase circuit?

What to do:

(*a*) To use a single-phase circuit, such as an ordinary lighting circuit, connect a Gramme ring coil, a lamp bank,



THREE PHASE FROM SINGLE PHASE

FIG. 101.

and a coil having self-induction as shown in Fig. 101. This produces in the Gramme ring coil a current which is approximately three-phase. Place on the coil a glass plate and sprinkle on the plate some iron filings. The filings are in constant motion showing that the magnetic field is constantly changing. Place an aluminum or copper cup bottom upward on a pointed support in the center

of the coil. The cup will rotate rapidly, the rotation being caused by the rotating magnetic field. Does the cup rotate in the same direction as the filings?

Currents are induced in the cup by the moving magnetic field. The cup then has a magnetic field of its own on account of the currents that are flowing round and round in it. The two magnetic fields, that of the cup and that of the coil, react upon each other so as to cause the cup to rotate. It is a magnetic pull which causes the rotation and we can show that the pull is in accordance with Lenz's law. If the cup were held at rest and the magnetic field allowed to rotate, the lines of force would move across the metal of the cup. According to Lenz's law the induced currents oppose this action and the cup is pulled along in the same direction as that in which the magnetic field is rotating. In other words, the induced currents attempt to keep the cup rotating as fast as the magnetic field rotates so that the lines of force cannot move across the cup.

(*b*) If any two of the connections at the coil terminals are changed, the direction of rotation is reversed. Try it. If the connections at one of the coil terminals is broken, the cup will not rotate. Try it.

With two connections only the current is single-phase. A single-phase current does not produce rotation. The purpose of the resistance and the self-induction coil is to split the phase, that is to make the current approximately three-phase. In a single-phase motor the magnetic field of the rotor itself after it is once started acts with the field of the stator or stationary part to produce rotation, hence the split-phase circuit is used only in starting.

(*c*) If there is a true three-phase circuit in the laboratory, the coil should be connected to this circuit using the three terminals indicated in paragraph (*a*) but omitting the lamp bank and the self-induction coil. A perfect

rotating field will be the result. The difference between the true three-phase field and the approximate three-phase field of paragraph (*a*) is shown in the different action of the iron filings.

Questions.—1. Why cannot a rotating field be produced by a direct current?

2. How are currents induced in the cup?

3. The cup represents the armature of an induction motor. Why is it not necessary to have any electrical connection between the armature of such a motor and the circuit which supplies current to the motor?

Materials Required.—Lamp bank; self-induction coil; Gramme ring coil. The Gramme ring coil may be constructed as follows:

A Gramme Ring Coil

To make a Gramme ring coil proceed as follows:

Procure circular motor stampings, 8 in. outside diameter, 5 in. inside diameter, having 24 slots forming 24 teeth projecting inward. These may be obtained from The Globe Electric Company, Chicago. Take enough of these stampings to make a thickness of 1 in. when clamped in a vise. Clamp the stampings together and wind with empire cloth to insure insulation of the core and prevent cutting insulation of the wire. Wind in each slot 120 turns of No. 22 magnet wire. Apply shellac after winding each layer. Mount the coil on a board and connect terminals of windings to binding posts. Be careful to connect so that when windings are connected in series the adjacent poles of two successive windings shall be of opposite kind. In other words, when connected in series the windings should be arranged as if the winding had been continued from one slot to the next in the same direction.

EXPERIMENT 126

PHASE TRANSFORMATION

Introductory Discussion.—The power of Niagara and other waterfalls is converted into electric power by means of water turbines driving large generators. These generators produce three-phase current. In the form of three-phase current at high voltage the electric power is transmitted over long distances. The voltage is stepped

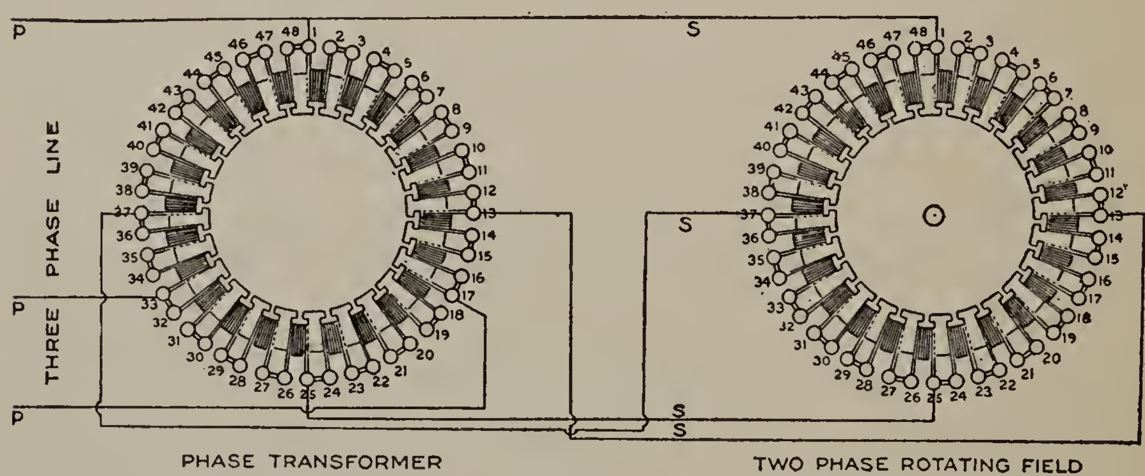


FIG. 102.

up or down as may be required by means of transformers. It is sometimes desirable also to change from three-phase to two-phase current. This can be done by means of a phase transformer.

What to do:

Arrange the connections of two Gramme ring coils as shown in Fig. 102. The three-phase circuit is connected to the first coil at three points 120° apart. 120° is the actual difference of phase between two of the electromotive forces in a three-phase circuit. This coil is then tapped at

four points 90° apart and wires from these four points connected to four corresponding points on the second Gramme ring coil. 90° is the phase difference between two successive electromotive forces in a two-phase circuit. The first coil is acting as a phase transformer. The second coil receives a two-phase current from the first coil.

Observe the rotation of the armature of the second coil. Reverse the connections of one phase of coil number two, that is, two connections that are directly opposite, 180° apart. What is the effect on the direction of rotation?

Make a sketch of your apparatus and connections.

Explain what is meant by a phase transformer.

Materials Required.—Two Gramme ring coils with armatures; three-phase circuit. If no three-phase circuit is at hand, an approximate three-phase current can be produced as in experiment 125 and this current used in place of the true three-phase current.

In order to better realize how the "Phases" are developed in a drum armature, take a piece of cross-section paper and draw upon it a circle whose diameter is ten large squares (see Fig. 103). Now draw two diameters as *AD* and *BF*. Draw also the equilateral triangle *ACE*. Suppose the circle represents a series of coils on the armature surface and that the points *A-B-C-D-E-F* are the ends of coils at the respective positions and are connected to slip rings. As the armature revolves in a magnetic field the voltage developed depends or varies as the position of the coil varies. Since the coils are all connected together, the voltage drop across any number of coils depends upon that number. Since the voltage varies from zero to a maximum, we will assume that we get a maximum at points *B* and *F*. Then across points *A* and *D* we would have zero. Now if we were to place a voltmeter across the points *A* and *B*, we would get a value between the maxi-

mum and zero. If the maximum value were 100 this value would be 70.7. If we were to read simultaneously the voltages of the points *AD* and *BF* for all positions of the coils and plotted curves for these voltages, we should find that we have two sine curves 90° apart. These two circuits when used together form what is classed as a two-phase circuit, collector rings *A-B-D-F*.

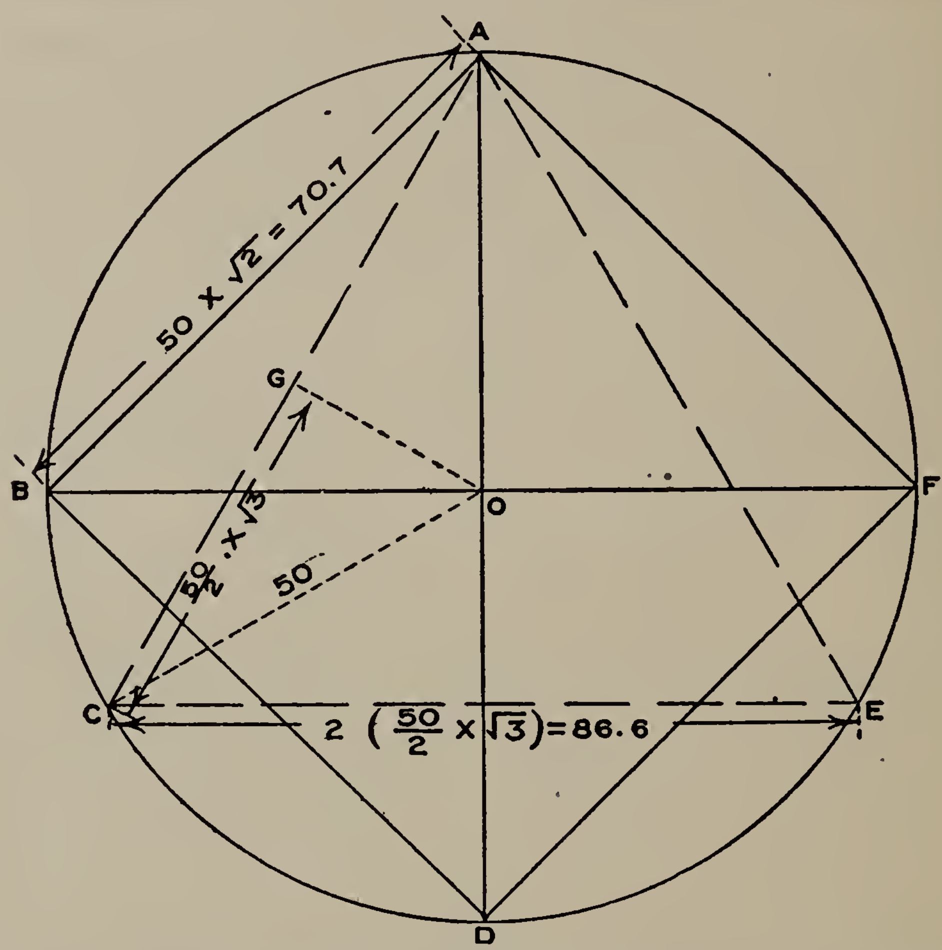


FIG. 103.—Relative voltages obtained by tapping the Gramme ring coil at various points. The same relations hold time for a drum-wound armature.

Similarly if we consider the waves formed by using collector rings *A–C–E* we would have three waves 120° apart. This gives the three-phase circuit. The circuits just described are common in rotary converters and can be obtained from any wave-wound armature by tapping in on the proper commutator bars.

Since the diagram has been constructed to scale the

relative voltages can be measured by means of a pair of dividers, or calculated by considering right triangles. For example $AO = 50$, $BO = 50$; therefore side $AB = \sqrt{50^2 + 50^2} = \sqrt{50^2 \times 2} = 50 \times \sqrt{2} = 70.7$. Similarly connecting points C and O and dropping OG perpendicular to AB from O, we get the right triangle OGC. In this $OC = 50$. Angle $GCO = 30°$ and angle $COG = 60°$. In a $30° - 60°$ triangle the side opposite the $60°$ angle is equal to $\sqrt{3} \times \frac{1}{2}$ the hypotenuse. In this case this would be $50/2 \times \sqrt{3}$. But since we wish the length of AC, which is twice CG, we get $2(50/2 \times \sqrt{3}) = 86.6$.

EXPERIMENT 127

THE AUTO-TRANSFORMER

Introductory.—The auto-transformer has a single winding tapped at a number of points. In other words, it is an impedance coil with a number of terminals. It is used where a number of different voltages are desired. The motor is fed from different points in the coil, the coil being connected across the supply circuit. The motor thus receives different voltages as needed.

What to do:

Connect the outside terminals of an auto-transformer

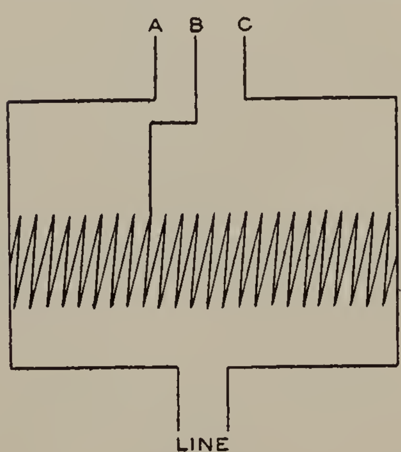


FIG. 104.

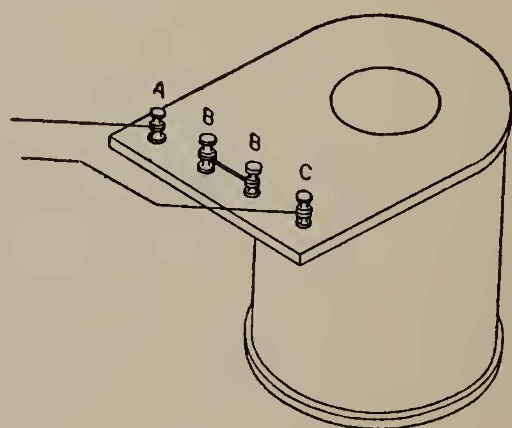


FIG. 105.

to the alternating-current line. With an alternating-current voltmeter take the voltage between one of the outside terminals and each of the inner terminals (Fig. 104). Take the voltage between the other outside terminal and each of the inner terminals. If the transformer set is used as shown in Fig. 105 there is only one inner terminal; binding posts *B–B* are connected by a short wire and form one terminal. In this case take three

voltmeter readings namely across terminals AB, BC, and AC.

Make a diagram like Fig. 104 and indicate on the diagram the voltages just found.

Materials Required.—Auto-transformer; alternating-current voltmeter.

EXPERIMENT 128

A BELL-RINGING TRANSFORMER

Introductory Discussion.—In a house having electric lights using an alternating-current it is economy to use a transformer in place of batteries for ringing door bells. Batteries must be frequently renewed at some expense while a good transformer will last a lifetime and cost nothing for upkeep nor does it add anything to the electric light bills. How can a device operate on an electric circuit without cost?

What to do:

(*a*) Connect a bell-ringing transformer as follows: Find the primary and secondary terminals and make the connections for a complete bell circuit as in Fig. 106.

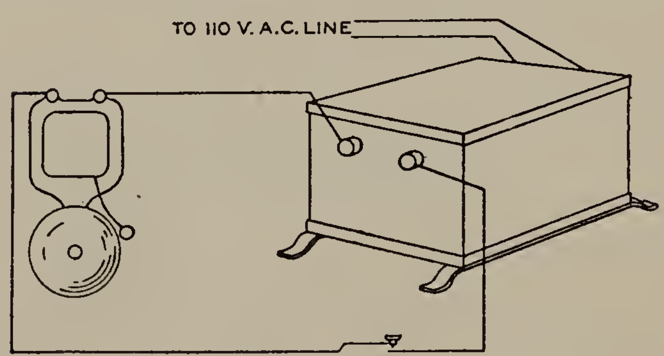


FIG. 106.

(*b*) With a voltmeter having a scale reading to 120 volts or more take the voltage across the primary terminals and then across the secondary terminals. Is the voltage stepped up or stepped down? Why?

(*c*) To find out why the transformer operates without cost make tests as follows:

Connect an alternating-current ammeter in the circuit as in Fig. 107. Take the ammeter reading with the bell circuit open, that is, the secondary coil on open circuit. Note that although the primary coil is connected across the line

thus forming a closed circuit, the current is practically zero. Explain this fact, recalling the experiment with the choke coil. (Exp. 116.)

Press the button and take the ammeter reading while the bell is ringing. How many watts, apparently, does the transformer consume?

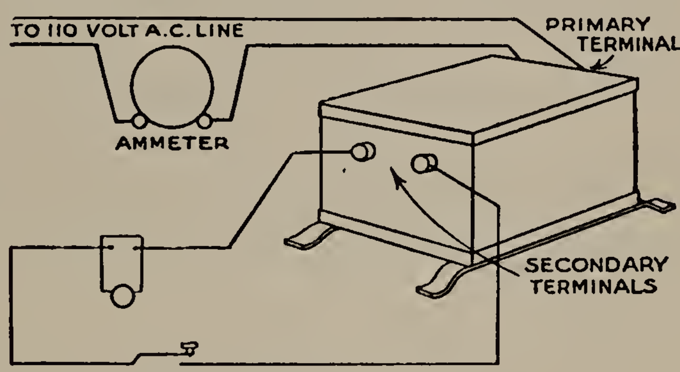


FIG. 107.

Connect the transformer through a watt-hour meter if one is at hand (see Fig. 108). Press the button and watch the meter to see if the disk rotates while the bell is ringing. An indicating wattmeter may be used in place of the watt-hour meter if the instructor prefers.

Why does it cost nothing for power to ring the bell?

Now short-circuit the secondary coil and read the wattmeter. The watts indicated are consumed in the transformer itself.

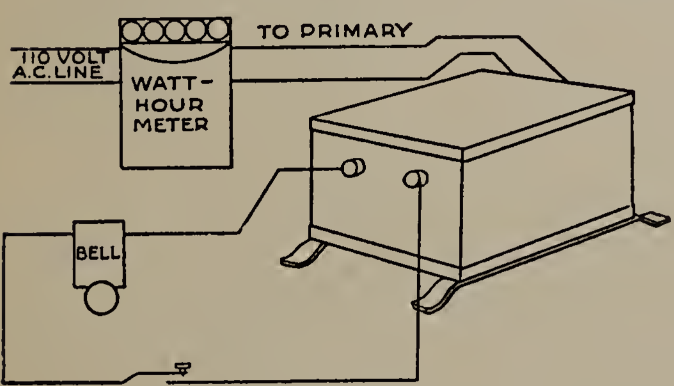


FIG. 108.

Do not conclude that the result obtained in this experiment applies to all transformers. If the power consumed when the bell is ringing were greater, about 8 watts or more, the result would be different.

Materials Required.—Bell-ringing transformer; buzzer; push button or contact key; wires for connections; alternating-current ammeter; alternating-current voltmeter; watt-hour meter or indicating wattmeter.

EXPERIMENT 129

A TYPICAL HOUSE LIGHTING SYSTEM

What is the general method of connecting lights to the main circuit? Why will no other method be just as good?

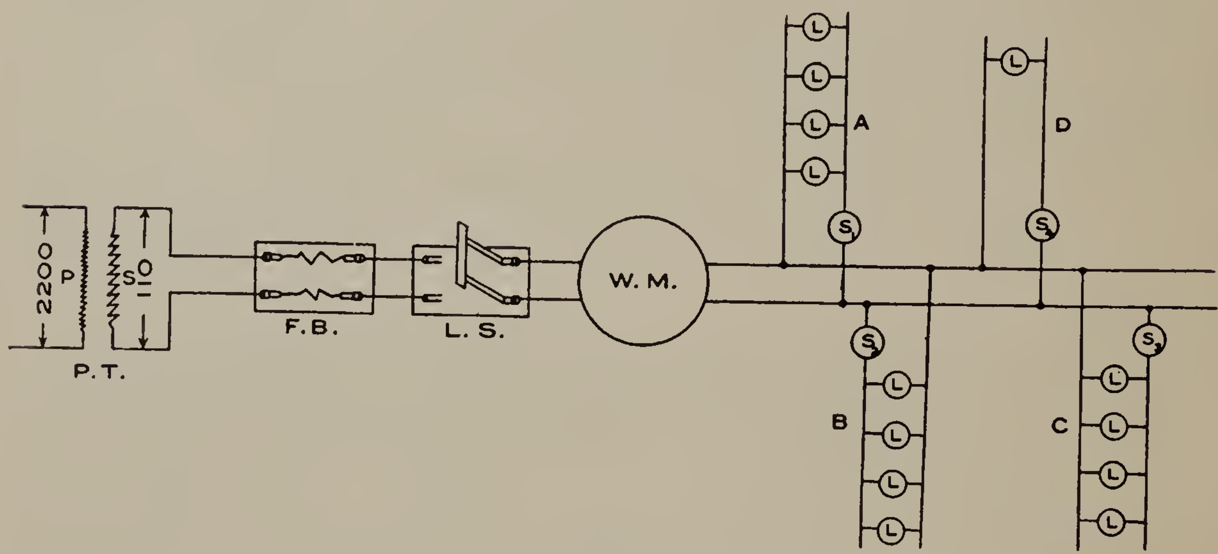


FIG. 109.

What to do:

(*a*) Connect the apparatus up as is shown in the sketch. (P.T.) is a pole transformer which reduces the voltage from the high pressure of 2,200 volts down to the regular house-lighting voltage of 110 volts. This transformer is generally located outside of the building, therefore, your circuit really starts at (F.B.), a fuse block which may be either of the plug, cartridge, or link type. From this the current should be made to pass through (L.S.), a double-pole, single-throw knife switch. This should be so connected that the current from the fuse block enters the clips of the switch while the blades pass the current on to the rest of the circuit. In other words, the switch

should always be so connected that the blades close in on the live side. From this switch the current should be passed through a recording wattmeter (W.M.). From here the current can be used wherever desired. As shown, circuits *A*, *B*, *C* and *D* might represent the different rooms of a home. These different circuits are each controlled by a single-pole snap switch.

NOTE.—Other circuits might be added provided the meter will permit, or some other electrical device such as a flatiron, toaster, or soldering iron might be substituted for any of them.

(*b*) Having connected the apparatus as directed in (*a*) make note of the reading of the meter. Then close the main switch. Turn on circuit (*A*) and allow it to run for 15 minutes. Again read the meter.

(*c*) Now keeping circuit (*A*) on add also circuit (*B*). Allow both of them to run for 15 minutes. Now read the meter.

(*d*) Finally allow the current to run for 15 minutes with all of the devices going at the same time. Record the meter reading at the end of the time.

(*e*) From the data just obtained calculate the power used by each of the circuits and from that the cost to operate each for a period of 4 hours, if current costs 10 cts. per kilowatt-hour.

(*f*) What would it cost to operate all of the devices at the same time for the same period of time?

(*g*) Now cut out all circuits with the exception of the single lamp. Does the meter register? Why should it?

Questions.—

1. How are all parts of branch circuits connected?
2. How many circuits might we have?
3. What determines the possible number?
4. What is the number generally used in practice?
5. How much current is allowed in each circuit?

Materials Required.—Fuse block (10 amp. capacity); two-pole, single-throw knife switch (slate base preferable); recording wattmeter; twelve incandescent lamps and sockets; four single-pole snap switches; several common electrical devices such as toasters, stoves, or soldering iron; wires; and tape for insulating the joints.

CAUTION.—Care should be taken that the circuits are so regulated that they do not draw a current which exceeds the capacity of the meter. This overload can be prevented if a fuse which is slightly lower in capacity than the meter is inserted in the fuse block.

EXPERIMENT 130

EFFICIENCY OF A TRANSFORMER

What to do:

(*a*) Connect a transformer, indicating wattmeter, alternating-current ammeter, alternating-current voltmeter, and lamp bank as in Fig. 110. The wattmeter must be in the primary circuit, the ammeter and voltmeter in the secondary circuit. The lamps must be suited to the voltage of the secondary. Assuming that the transformer steps up the voltage from 110 to 220, the lamps may be

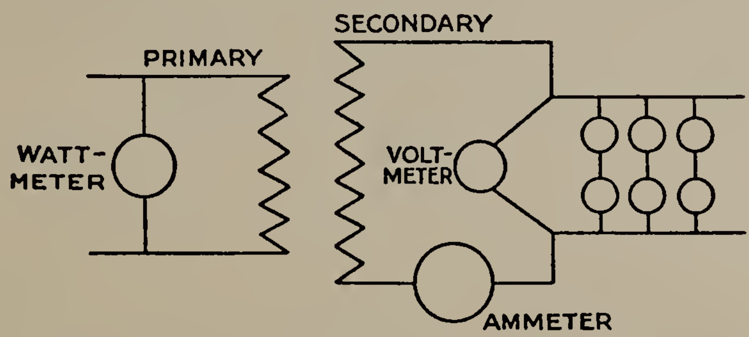


FIG. 110.

connected, as in the diagram, in groups of two, the two lamps in each group being in series and the groups being in parallel.

(*b*) Turn on one group of lamps. From the voltmeter and ammeter readings compute the output in watts. The wattmeter gives directly the input in watts. From these two results find the efficiency.

(*c*) Turn on a second group of lamps and again find the efficiency.

NOTE.—The ammeter and voltmeter cannot be used in the primary circuit on account of difference of phase between current

and voltage, that is, the lag of the current. In the lamps there is no lag. A watt-hour meter may be used in place of the indicating wattmeter. Make the connections as shown in Fig. 111. The number of watts is then found as follows: Count the number of revolutions the disk makes in 1 minute and from this compute the number of revolutions per hour for the circuit you are

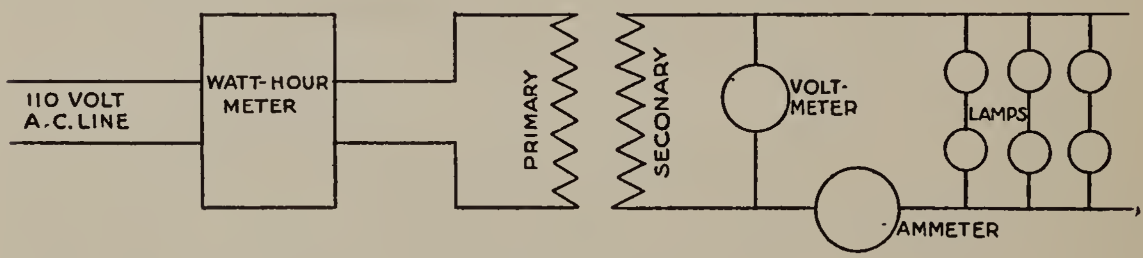


FIG. 111.

testing. Multiply this number by the decimal fraction marked on the disk. This gives the number of watt-hours in 1 hour and therefore the number of watts.

Materials Required.—Transformer; lamp sockets with porcelain base; alternating-current voltmeter; alternating-current ammeter; indicating wattmeter.

EXPERIMENT 131

THE MAGNETO

Introductory Discussion.—Three important principles of induced voltage may be illustrated by means of a magneto. It is necessary for two pupils to work together in performing this experiment.

What to do:

(*a*) Hold the terminals of a hand magneto in your hands while your partner turns the armature slowly. Note that the armature cuts the lines of force of the permanent magnet. Do you feel any evidence of induced voltage? State the cause of this induced voltage.

(*b*) Let the armature be turned a little faster. What about the voltage induced when lines of force are cut at greater speed?

(*c*) While your partner turns the armature, touch the terminals together so as to short-circuit the armature. Does the induced current favor or oppose the motion of the armature?

Materials Required.—Small hand magneto.

EXPERIMENT 132

SOUND

RATE OF VIBRATION OF A TUNING FORK

Introductory Discussion.—The instructor should prepare the plates in this experiment and the pupils should count the number of vibrations per second from the plate.

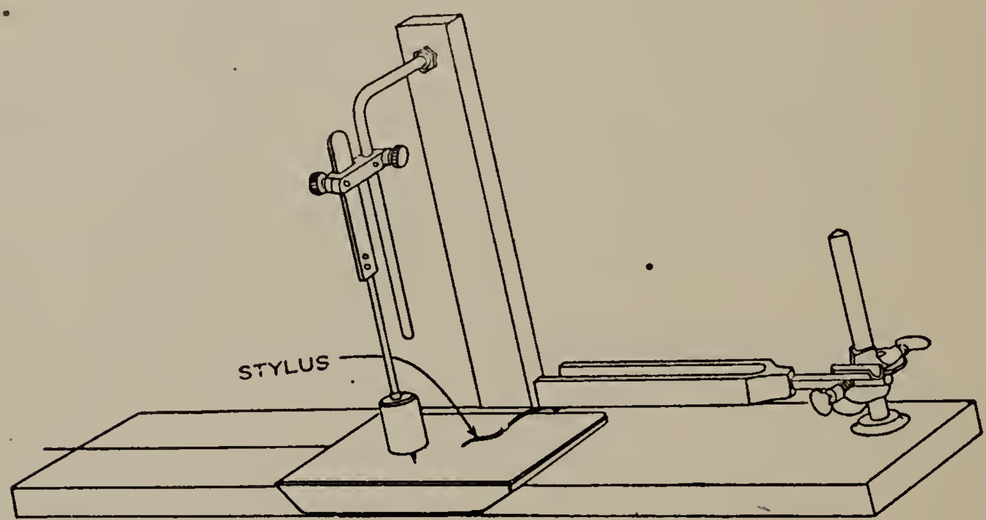


FIG. 112.

The pendulum (Fig. 112) should be adjusted to beat half seconds. The pendulum is set swinging, then the fork struck with a wooden mallet and the plate which has been prepared by coating it with a solution of whiting and alcohol is drawn quickly under the pendulum so that the stylus on the pendulum and the one on the fork both mark tracings on the glass plate.

What to do:

Count the number of vibrations made by the tuning fork during one complete vibration of the pendulum.

From this result find the number of vibrations per second of the tuning fork. Make the count three times using different plates. Record the three readings and the average.

Materials Required.—Apparatus as shown in Fig. 112.

EXPERIMENT 133

RESONANCE AND WAVE LENGTH

Introductory.—If the prongs of a vibrating tuning fork are placed over a jar the depth of which is one-fourth the wave length emitted, there will be a sudden and noticeable increase in the volume of sound given off. This phenomenon is known as *resonance*, and is due to the combination of the direct and reflected waves.

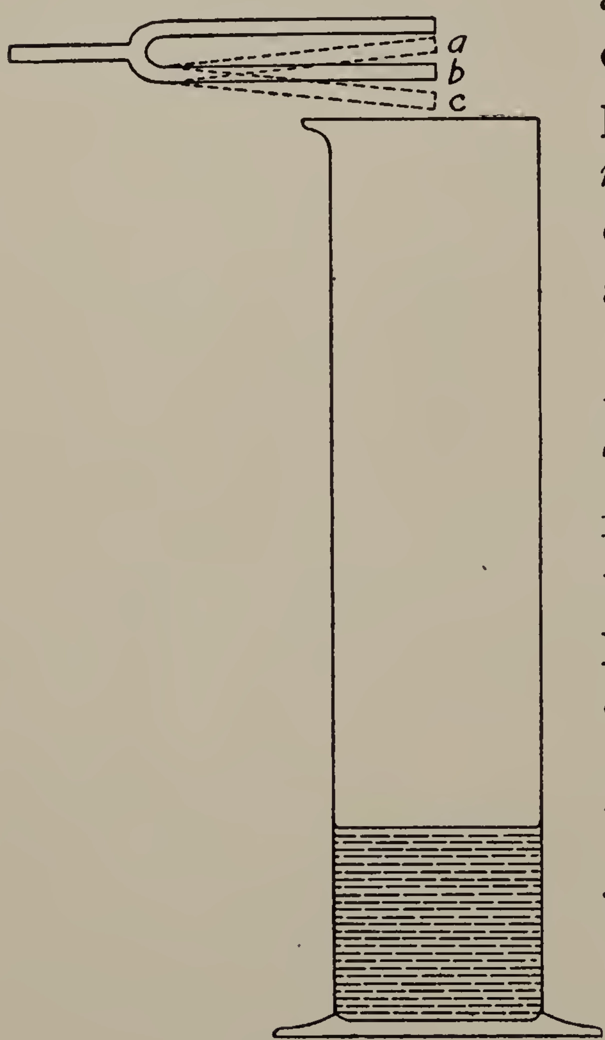


Fig. 113.

Suppose a prong start from the position *a* (Fig. 113). The direct wave merely follows the wave downward to *c*. But the instant the prong starts from *a* it starts a wave (condensation) down the jar. If this impulse can travel to the bottom of the jar and back again to *c* by the time the prong reaches *c*, the two waves combine and produce a considerably louder tone. Then this reflected wave has traveled a half wave length while the prong moved from *a* to *c*; in other words, the jar has a depth of one-fourth the total wave length.

What to do:

(*a*) Secure a tall glass jar (hydrometer jar). Have ready a beaker of water. Set your tuning fork into vibration, and hold the prongs over the mouth of the jar parallel to the table top. Notice whether there is any reinforcement of sound as the prongs are moved back and forth across the mouth of the jar. If not, pour a little water into the jar, and try again. Repeat operations till you reach a point where the two waves (direct and reflected) unite in a greatly increased sound.

(*b*) Measure the distance from the mouth of the jar to surface of the water, remembering that this is about one-fourth the total wave length. Compute the latter.

(*c*) An important correction is needed in the computation of wave length as found in (*b*). The wave really travels farther than determined there since the wave reflects on the sides of the jar and spreads out somewhat at the mouth. Therefore add 0.4 the diameter of the jar to the length of the air column as found in (*a*). The sum is one-fourth the total wave length.

(*d*) Tabulate as follows:

Length of resonating air column........................
Interior diameter of jar..............................
Corrected air column length...........................
Total wave length as found............................
True wave length as computed $\left(\frac{v}{n}\right)$ ....
Vibration rating of fork...............................
Temperature...
Velocity of sound in air at this temperature.............

Materials Required.—Tuning fork of known frequency; hydrometer jar; beaker.

EXPERIMENT 134

THE SONOMETER

How are the rates of vibrating strings affected by length, tension and weight?

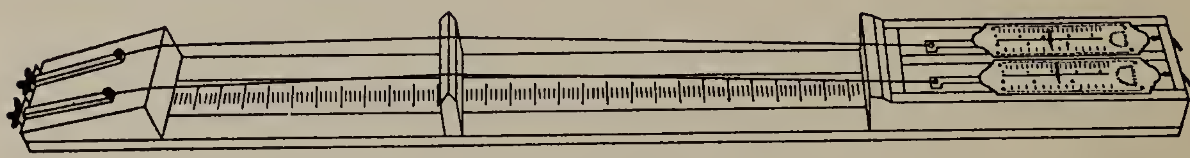


FIG. 114.

What to do:

(*a*) Pluck or bow a string near one end till it vibrates as a whole, giving off its fundamental tone. Now move the bridge to a point midway between the two ends and cause the string to vibrate again. What difference in pitch do you observe as compared with that of the string vibrating as a whole? If in doubt, remove the bridge and repeat, substituting your finger for the bridge and repeatedly getting the tone of the entire string and then of the half string. State the relationship between length and pitch.

(*b*) Adjust tension till both strings are in perfect unison. Now pluck one: after a moment damp it with the finger and notice the other. Is it in vibration? What tone does it emit? Repeat to make sure of results. Change the tension and repeat. Are the results the same? Vibrations produced in one body by another nearby having the same frequency are known as *sympathetic* vibrations.

(*c*) Adjust the tensions till two wires are in perfect unison. Put the bridge under one wire exactly midway between the two ends, and place riders (paper stirrups V-shaped) on the short wires. Now bow the long wire. Are the short ones affected? If so, what tone do they emit?

(*d*) Put the bridge under one wire exactly one-third the distance from one end. Place riders on both sides of the bridge exactly in the middle of the short strings. Bow the free (without bridge) wire. Results on the two short wires? If they vibrate, what are their vibration rates and tones emitted as compared with the fundamental?

(*e*) Repeat (*d*), placing bridge one-fourth the distance from one end. Results? Vibration rates of short wires? How are all these frequency rates related to the frequency of the fundamental? What, then, are *overtones?* Set down the frequency rates you have obtained, and find their greatest common divisor. How is this number related to the rate of the fundamental?

(*f*) Adjust the tension of the two strings on the apparatus till in perfect unison, getting, however, the lowest tension rather than the highest possible. Suppose this to be 4 lb. each. Then increase the tension of one string till the fundamental tone emitted is exactly one octave higher than the fundamental of the other string. What is the tension on the string of higher pitch? Can you state a proportion showing the relation between *frequencies* and *tension?*

(*g*) The strings on a violin are all of one length but of different weights. How do these different weights affect the pitch? If possible, equip your sonometer with one wire having twice the diameter of the other. Adjust the tensions till they are equal. Now sound the wires in unison. The two wires having the same length and tension should now emit tones one octave apart. Do they? Since the diameters of these wires are as 2 to 1, their weights must be as 4 to 1 (Why?). Can you state the inverse proportion showing the relation of *frequencies* to *weights?*

Materials Required.—Sonometer of two or more wires; bow; paper riders.

EXPERIMENT 135

REFLECTION IN A PLANE MIRROR

What to do:

(*a*) Plane mirrors are of two kinds—silvered glass, and polished metal (nickel). If your mirror is of the former kind, its plane of reflection lies on the back of the glass; if metal, the front side is the reflector. Determine with which kind you are to work.

(*b*) On the 10-cm. line (abscissa) set up your mirror, and draw a light pencil mark on the paper along the edge of the reflecting side. This line represents approximately a line in the plane of reflection.

(*c*) Now perpendicularly to the board set a pin some 4 cm. in front of mirror and about 3 cm. to the left of the middle of the paper (C, Fig. 115). Set another pin to the right of the middle (D). Now sighting over C into the mirror, find the image of D reflected at D', and set another pin in the line CD'. Similarly, sighting over D, set a pin at F (any convenient place in the line with D, and the image of C as seen back of the mirror).

(*d*) Set a fifth pin at G in line with D and its image D'.

(*e*) Removing the mirror from the paper and using a ruler, connect C and E, extending it indefinitely back of the line MN as a dotted line. Then connect D and F extending till the line meets EC at O. Connect D and G, extending the line back of MN as a dotted line till it intersects CE at D'.

(*f*) At the point O erect a perpendicular OK making the angles a and b. A ray of light passing from D to O will be reflected back along the line OC making the angle of incidence b and the angle of reflection a. With a pro-

tractor measure the angles you have thus obtained. Are they equal?

(*g*) Another characteristic of images seen in a plane mirror is that they appear as far back of the mirror as the object is in front. Since *D* represents a point in one of the objects reflected in the mirror, and since *DH* is per-

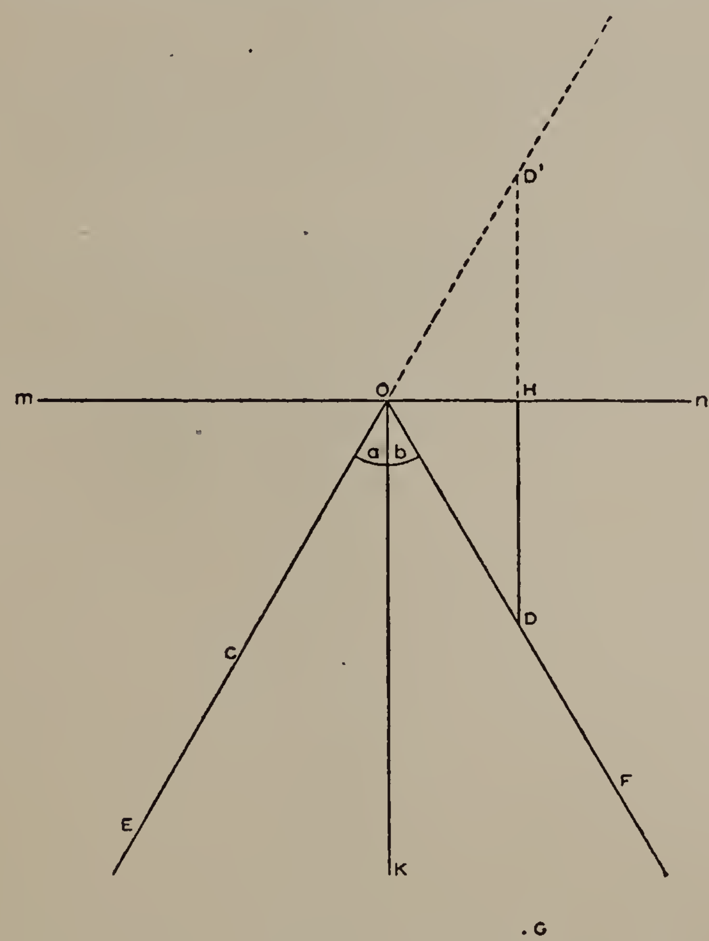


FIG. 115.

pendicular to *MN* (Why?), *HD* should be equal to *HD'*. Measure the two lines and find out whether they are equal.

(*h*) What are the two characteristics of images seen in a plane mirror? Would the image of a tree standing in a pond and reflected from its surface have the same or a different size from that of the tree itself? Would the image appear upright or inverted? Why?

Materials Required.—Plane mirrors; drawing board; pins; cross-section paper.

EXPERIMENT 136

THE PERISCOPE

What is the main object of the Periscope?

Where can it be used to great advantage? Why?

What to do:

(*a*) A simple yet efficient periscope can be made by supporting two mirrors as indicated in the diagram. Secure

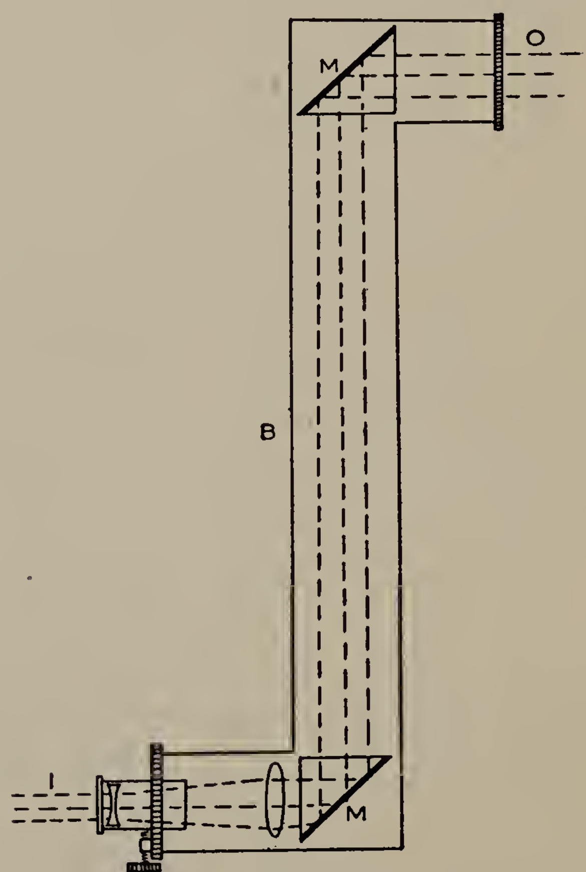


FIG. 116.

a box (*B*). This can be made any desired length or shape, however, a box 4 by 4 by 20 in. is most convenient. This box should have near the ends and on opposite sides two openings (*O* and *I*). These should be about the size of the mirrors used and should be shielded by having over

them hoods. These can easily be made by fastening over them small boxes which have their ends removed. Place the mirrors inside the large box so that they have the reflecting sides are facing each other and are parallel, but make an angle of about 45° with the opening. Your periscope is now ready for action. The principle of operation is simple. Any object placed in front of the opening *O* will be seen at the opening *I* as an image of an image. Show this by means of a good drawing. Is the image as seen erect or is it inverted? Why?

(*b*) In the finer instruments right prisms are used in place of the mirrors and a telescope is used in front of opening *I*. What is the effect of the telescope?

Materials Required.—Periscope constructed as given above; and a small telescope.

EXPERIMENT 137

REFLECTION BY CURVED MIRRORS

Part I. Concave

What to do:

(*a*) Set the lamp and screen side by side. Then move the mirror back and forth on a line perpendicular to line joining lamp and screen till object and image appear to have the same size. Clamp the mirror rigidly in this

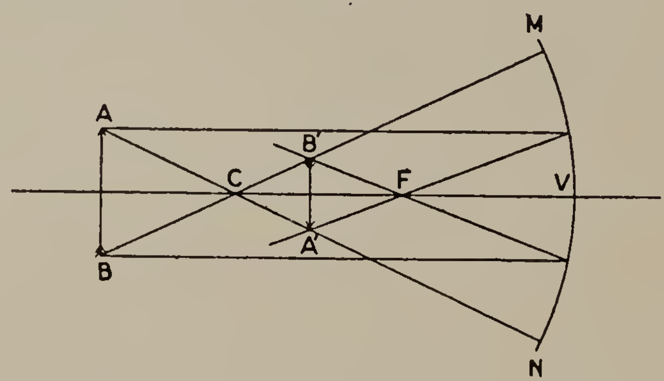


Fig. 117.

position, and study the image carefully. Is it upright or inverted? You can examine the image to better advantage by cutting off the lamp light by a screen of some size (drawing board is excellent).

(*b*) The object by this method is approximately at the center of curvature (C). A line drawn through this point and the center of the mirror is the *principal axis*. The point on this line midway between C and the center of the mirror (V) is known as the *principal focus*, because all lines drawn parallel to the axis after reflection converge on this point.

(*c*) Now move the object (lamp) to some distance (say 3 ft.) beyond C and adjust the screen till a clear though re-

duced image is seen. Is the image inverted or erect? Where on the axis is the image located—at C, or F, or between them? Try moving the object still farther away. What is the effect on the image?

(*d*) Now move the object to a point on the axis just inside C, and adjust the screen till a clear image is seen. How do object and image now compare in size? Move the object as near to F as you can get it and get an image. Do not be surprised if the image appears indistinctly defined on a distant wall of the room. Is it inverted or upright?

(*e*) Move the object to F, and try to adjust the screen for an image. Can you get one?

(*f*) Now move the object inside F. As the image obtained from this location is virtual, it will not appear upon the screen but can be seen by a front view as though standing in behind the mirror. Try shifting the object back and forth on the axis F and V. In which location is the image largest?

(*g*) Record results as follows:

Object	Image			
	Location	Erect or inverted	Kind	Size
Outside C..................				
At C........................				
Between C and F...........				
At F........................				
Between F and V...........				

Location of object to secure largest real image............

Location of object to secure largest virtual image.........

Part II. Convex

(*h*) Carry through for this mirror all the tests for the concave reflector. Can you find any case in which object and image are the same size? Any case of enlargement of image?

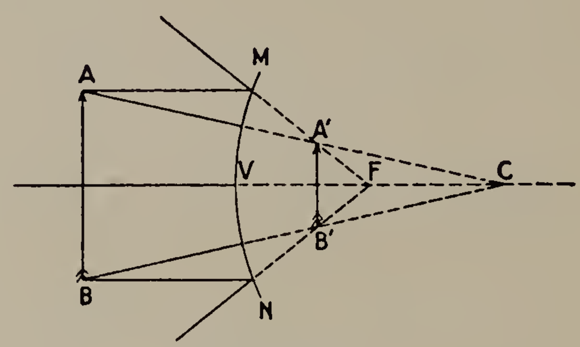


Fig. 118.

(*i*) Make drawings to illustrate the image obtained in each of the cases developed above—5 for the concave mirror, and 1 for the convex.

(*j*) If an automobile driver wants the road in front of his machine illuminated, where on the axis of the reflector of the lamp should he place the light? If he wants a view of the road behind him, which of these reflectors should he select?

Materials Required.—Convex and concave mirrors; screen; source of light (gas flame or electric light); darkened room.

EXPERIMENT 138

SHADOWS

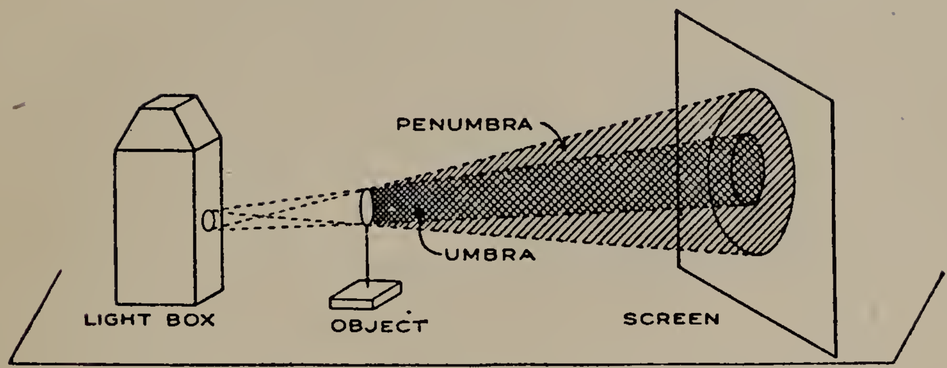


FIG. 119.

What is a shadow?

What to do:

(*a*) Secure a source of light which has a rather large area, (an ordinary gas flame or light box with full opening will do). Allow the light to fall upon a screen (a piece of cardboard 12 in. square is large enough). Hold some object about the size of a half dollar between the source of light and the screen. Note the character of the "shadow" cast upon the screen. You will find that there are two parts: (1) a dark part which is called the "*umbra;*" and (2) a lighter part called the "*penumbra.*" If you do not get these two parts at first, move the object toward and away from the source of light *slowly* until you find the place at which you get the best results.

(*b*) Now replace the large source of light by a small electric light (pocket flashlight size) or use in place of the large area of the light box a small circular hole about the size of a lead pencil. Again observe the shadow of the object used in paragraph (*a*). How do the umbra and

penumbra of this case compare with those of the previous one? Explain.

(*c*) Make a good diagram to illustrate the condition of both cases (1) with a large luminous body, (2) with a small luminous body.

(*d*) From your observations what determines the character of the shadow cast by light sources?

Materials Required.—Optical light box or gas flame; screen; and an opaque object.

EXPERIMENT 139

INTENSITY OF ILLUMINATION

Suppose you are reading by a lamp which is 3 ft. from your book. If you move until the book is 6 ft. from the lamp, how much less light falls upon the book? If you move still farther away from the lamp, at what rate does the intensity of the light diminish?

What to do:

(*a*) Prepare two pieces of cardboard as follows: In one piece cut a hole 1 in. square. Call this card *A*. Rule the other card in 1-in. squares. Call this card *B*.

(*b*) Place *A* 6 in. from a small source of light such as a gas flame turned low. Hold *B* 12 in. from the light so that the light passing through the hole in *A* falls upon *B*. The edge of this light spot should be distinct. If it is not, turn the flame lower.

If the light which passes through the hole were stopped at *A*, it would cover just 1 sq. in. since that is the area of the hole. The light that would fall on 1 sq. in. on *A* is over how many square inches on *B*? Then the light on 1 sq. in. on *B* is what fraction of the light on 1 sq. in. on *A*? This fraction represents the intensity of the light on *B* as compared with the intensity of the light on *A*. That is, if the intensity on *A* is taken as 1, the fraction just found is the intensity on *B*. If you double the distance from a source of light, what of the intensity of illumination?

(*c*) Without moving *A* place *B* 18 in. from the flame and answer the same questions as in paragraph (*b*). If

you make the distance from a source of light three times as great as at first, what of the intensity? What relation is there between the intensities of light on A and B, and their distances from the source of light? State this relation in the form of a proportion, letting I_1 and I_2 represent the intensities and D_1 and D_2 the distances. Test your proportion by substituting the values obtained in your experiment for the letters.

Materials Required.—Meter stick with support and clamps; gas jet or light box with small opening; cardboard.

EXPERIMENT 140

THE PHOTOMETER

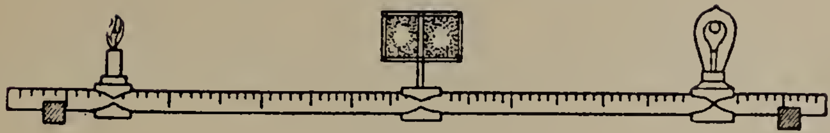


FIG. 120.

What particular gain is there in knowing the candlepower of any given light?

What to do:

(*a*) Set up a Bunsen photometer as shown in the diagram. Place a standard candle at one end and an ordinary oil lamp at the other. Adjust the *spot* so that the illumination from both sources of light is the same. Make note of the distance from the spot to the candle and from the lamp to the spot. Now calculate the candlepower of the lamp, knowing these two distances, by means of the following formula,

$$\text{candlepower of unknown} = \text{candlepower of standard} \times \frac{(\text{distance from spot to unknown})^2}{(\text{distance from spot to standard})^2}$$

(*b*) Find in a similar way the candlepower of the lamps ndicated in the table below and record your results in the tabular form as shown.

Suggestions.—In finding the candlepower of the various-sized electric lights, it will be well to use a 60-watt lamp, whose candlepower has been previously determined, as the standard and compare the other lamps to this. In

order to get the energy consumed it will be necessary to connect a wattmeter or volt and ammeter in circuit with the unknown.

Kind of lamp	Power consumed in watts	Distance from spot to		Candlepower	
		Standard	Unknown	Calculated	Per watt
Oil..................					
Gas..................					
Welsbach.............					
4-cp. carbon.......					
16-cp. carbon.......					
32-cp. carbon.......					
40-watt tungsten....					
60-watt tungsten....					
60-watt nitrogen....					
1,000-watt nitrogen....					
Arc lamp............					

Questions.—Of what commercial value is the candlepower determination? Why do we not use arc lamps to light our homes?

Which of the lamps as determined above gives the most light for the least cost?

Note.—A large number of lamps has been indicated so that a selection according to the lights available can be made.

Materials Required.—Bunsen photometer; lamps as indicated in the table; wattmeter or volt and ammeter, standard candle; ordinary oil lamp; and a Welsbach burner.

EXPERIMENT 141

REFRACTION IN WATER

Of what value is refraction in water?

What to do:

(*a*) Secure a 1-qt. rectangular battery jar. Fasten over one of the large sides a piece of paper large enough to cover the entire side and which has cut out of the center a 3-in. circle. Now with some waterproof ink or paint mark off a vertical and a horizontal diameter. Divide the circumference into degrees. To prevent the markings from being washed off and the paper from becoming wet, paraffin or shellac the surface after having marked it. Cut a narrow slit in a piece of cardboard and place it in a horizontal position over the opening of a light box having preferably a 60-watt nitrogen lamp as the source of illumination. This will give a very powerful narrow beam of light.

(*b*) Now by means of a plane mirror supported on a ring stand reflect the beam of light into the jar which is filled with water up to the horizontal axis, so that the beam passes through the intersection of the vertical and horizontal axes. By varying the position of the mirror any desired angle can be obtained between the ray of light and the water surface.

(*c*) Referring to the sketch *IO* is called the *incident* ray and *RO* is called the *refracted* ray. Angle *YOI* is called the

angle of incidence and *Y'OR* is called the *angle of refraction.* By carefully observing the ray of light determine the angles of incidence and refraction for at least five positions of the beam.

(*d*) Now from the functions of angles table given in the appendix, determine the values of the sines of the various

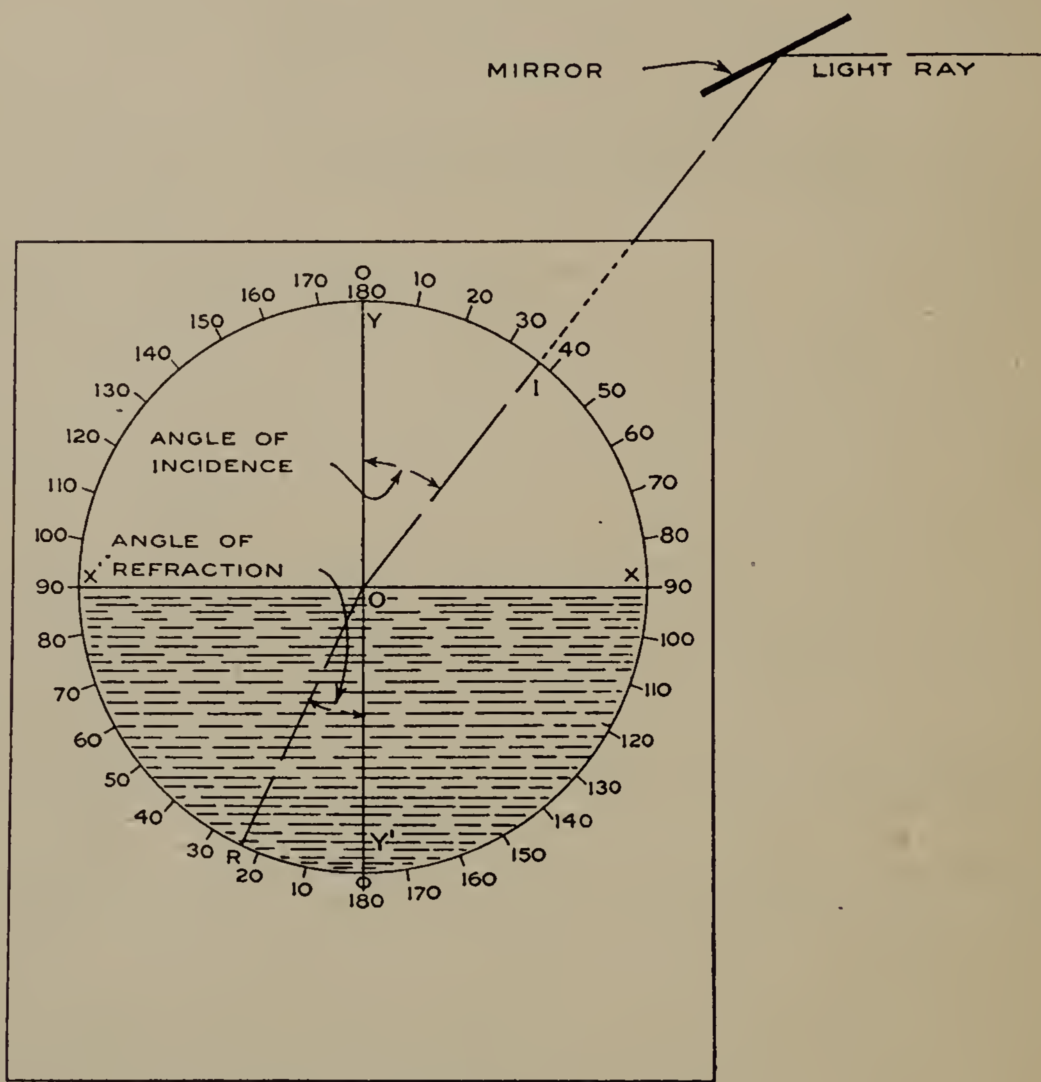


FIG. 121.

angles used above, and from these values by use of the following formula calculate the index of refraction of water.

$$\text{Index of refraction} = \frac{\text{sine of incident angle}}{\text{sine of refraction angle}}.$$

Record your results in the following form:

Trial	Angle of		Index of refraction
	Incidence	Refraction	

Materials Required.—Refraction apparatus; mirror and support; light box fitted with a 60-watt nitrogen lamp.

EXPERIMENT 142

REFRACTION IN GLASS

Introductory Discussion.—The purpose of this experiment is to determine the ratio of the speed of light in air to the speed in glass. This ratio is called the index of refraction for glass. The greater the index of refraction the greater is the bending of the light.

What to do:

(*a*) Draw a straight line on your note paper using a ruler and a well-sharpened pencil. Lay the plate glass on this

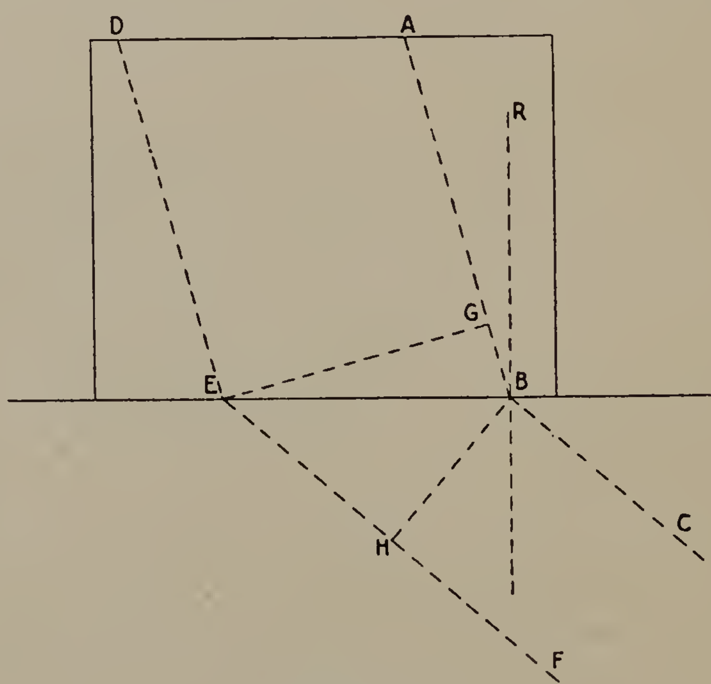


Fig. 122.

paper with one of the polished edges (*EB*, Fig. 122) on this line. Place two pins in contact with the polished edges as at *A* and *B*, so that a line joining the pins will form an oblique angle with each of the edges. The larger the angle *AB* makes with the perpendicular *BR*, the better. Now

set a third pin at C so that C, B, and the image of A seen through the glass appear to be in one straight line. Sight along the line of the pins carefully with the eye on a level with the glass. BC is then the direction of the light from the pin as it passes from the glass to your eye, that is the direction of the light beam in air. AB is the direction of the light beam in the glass. The beam is evidently bent at B.

(*b*) Draw a line DE parallel to AB. This must be done accurately. Draw EF parallel to BC. These lines with those previously drawn represent the bending of a parallel beam of light passing from glass into air. Draw EG perpendicular to AB from the point E and HB perpendicular to EF from the point B. Draw accurately using a protractor or the geometrical construction for dropping a perpendicular from a point to a line. EG represents the front of the light wave as it is about to emerge from the glass. HB represents the front of the wave in air. The part of the beam which emerges at E travels in air from E to H in the same time that the part of the beam at G travels from G to B. The ratio of EH to GB, therefore, is the ratio of the speed of light in air to the speed of light in glass. Measure these lines carefully in millimeters estimating to tenths of a millimeter and find the ratio $EH:GB$.

Materials Required.—Plate glass with two opposite edges polished; pins; ruler; protractor.

EXPERIMENT 143

TOTAL REFLECTION

What to do:

(*a*) Place sheet of paper down on drawing board. Put the glass cube down on sheet of paper, and trace its boundaries lightly with a pencil, lettering as shown in Fig. 123.

(*b*) Stick a pin in the line BC, and look through the glass along AB. Can you see the pin through the glass at all? Try shifting the pin to various locations between B and C. Result?

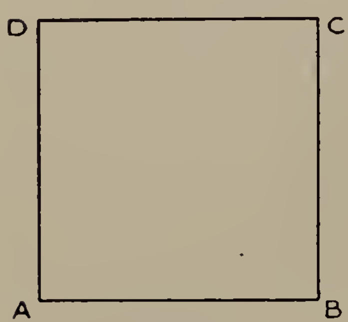


FIG. 123.

(*c*) Move pin to DC and look through the glass toward the line BC. From what point does the ray of light from the pin appear to come? Has the face BC now become a perfect mirror? Test by sticking pins in the board (1) at the point of reflection, and (2) at the point of emergence in AB, erecting a perpendicular at point of reflection, and comparing angles of incidence and reflection. Measure either angle with protractor, and compare with the critical angle for crown glass (41°).

(*d*) Holding a tumbler half full of water some distance above the eye, thrust a pencil part way down through the water. Looking upward through the side of the glass toward the pencil, can you see all of it? Which part is visible? Can you see an image of part of the pencil as well as the pencil itself?

(*e*) Holding the tumbler of water as in (*d*), pass to the window of laboratory and in the same way look at familiar objects outside the window. Is your water surface a perfect mirror? Substitute for the water mirror a silvered plane mirror and repeat. Do you find that at all angles your water mirror is equally good? What, then, is the critical angle?

Materials Required.—Plane mirror; glass tumbler; glass cube, 5 cm. edge; pins.

EXPERIMENT 144

LENSES

Introductory.—Lenses are of two general classes, convex and concave. A convex lens is thicker in the middle than at the edge. A convex lens may be convex on both sides or convex on one side and plane on the other. It may even be convex on one side and concave on the other but if there is a greater curvature on the convex side than on the concave side so that the lens is thicker in the middle than at the edge, it belongs to the class of convex lenses.

The use of both classes of lenses will be made clear as we proceed with this series of experiments.

What to do:

(*a*) To find the *principal focus* and *focal length* of a convex lens.

If possible to work in the sunlight, proceed as follows: Hold a convex lens so that the sunlight passing through it falls upon a sheet of paper. Move the lens nearer to or farther from the paper until the spot of light is as small and bright as possible. The light is then "focused" on the paper and the spot of light on the paper is at the principal focus of the lens. Measure the distance between the lens and the spot on the paper. This distance is the *focal length* of the lens.

If it is impossible to work in the sunlight an image of any distant object may be thrown on the paper by means of the lens. Such an image is very near the principal

focus and the distance between the lens and this image may be taken as the focal length of the lens.

The *principal focus* of a lens is the point at which a parallel beam of light is brought to a focus. A beam of sunlight is a parallel beam. A beam of light from an object at a distance of 100 ft. or more falling upon a small lens is very nearly a parallel beam.

(*b*) Forming a real image without a lens.

Make a hole about the size of the head of a pin in a piece of cardboard. Call this card *A*. Use another card *B* to receive the image. Place *A* between a candle flame or other luminous object and *B* so that the light from the flame can pass through the pinhole and fall upon *B*. Adjust the distances of the cards from the flame until you have an image of the flame on *B*.

It may be necessary to place *A* 3 or 4 in. from the flame and *B* 3 or 4 in. from *A*. After getting the image distinct move *B* farther from *A*. How does this affect the size of the image?

Make the hole larger, about ½ in. in diameter. How does this affect the brightness of the image? Is the image as distinct as before; in other words, would you call it as good a picture of the flame having the edges as sharp and distinct as before?

(*c*) You have found that an image can be formed without a lens. The next step is to see if there is any advantage in using a lens.

Support the convex lens close to card *A* so that the card is on the side of the lens toward the candle. The light passing through the hole in the card will then pass through the lens (Fig. 124). Place the candle about 50 cm. from the lens and move card *B* back and forth until a distinct image of the candle is seen on *B*. Is this image more or less distinct than the one obtained with-

out the aid of a lens? Draw a diagram to explain your answer.

(*d*) Move the candle nearer to the lens and then move card *B* until the image is again distinct. When the object (the candle) is moved nearer to the lens, is the image farther from the lens or nearer to it? Does the image then become smaller or larger?

(*e*) Place the candle at the principal focus, that is at the same distance from the lens as the focus of a beam of sun-

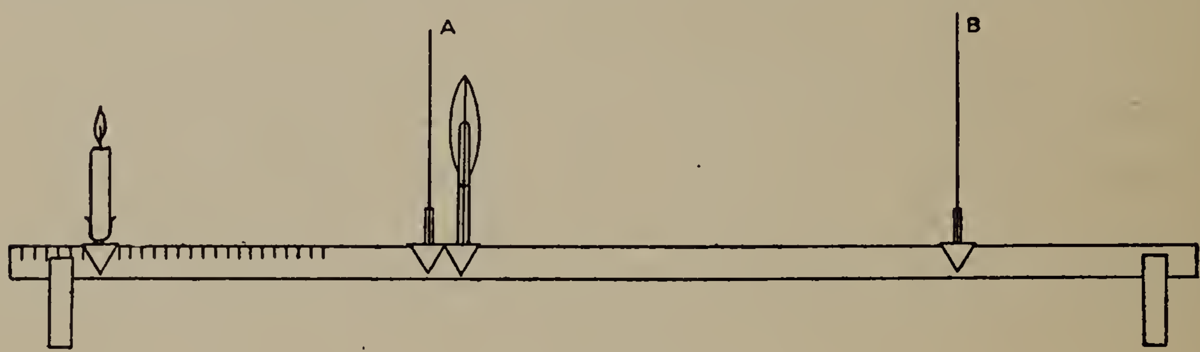


FIG. 124.

light found in paragraph (*a*). Do you get a distinct image of the candle on card *B*? Place the candle still nearer to the lens. Do you get a distinct image? Make a diagram to show how the light is acted upon by a lens when the source of light is farther from the lens than the principal focus (see Fig. 124*A*).

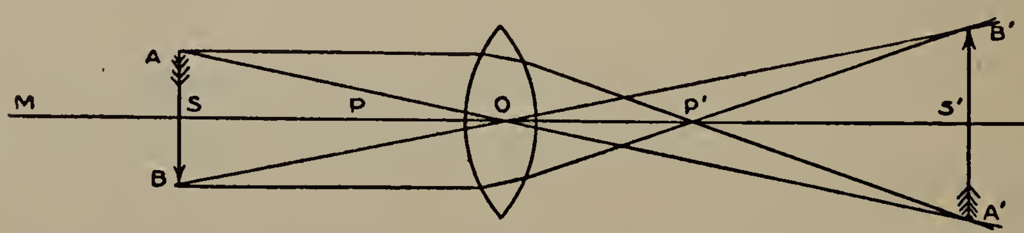


FIG. 124*A*.

(*f*) Remove card *A*. Light will then pass through the entire lens instead of a small portion at the center. Is the outline of the image as distinct as before? The outer part of a lens does not focus the light at quite the same distance that the center does.

(*g*) Remove the convex lens and place a concave lens between the candle and card *B*. The source of light should be small (turn the flame low if gas is used). A circle of light is seen on *B* but no image. Move *B* farther from the lens. Does the circle grow larger or smaller? Does the lens spread the light or bring it to a focus? Look through the lens toward the candle. You see a virtual image. Make a drawing to show how a concave lens acts on a beam of light. Why does the concave lens not form a real image on the cardboard screen?

(*h*) Again place the convex lens in position and adjust card *B* to get a distinct image. Now place another convex lens close to the first. Move *B* until the image is again distinct. Is the image nearer to the two lenses than it was to the one lens or is it farther away? Why?

(*i*) If you have a concave lens of slight curvature and a convex lens of greater curvature make the following test. Place the convex lens in position and adjust *B* for a distinct image. Place the concave lens close to the convex lens and again adjust *B*. Is the image now farther away or nearer to the lens? Why?

Questions.—1. If the lens of the eye forms an image in front of the retina what kind of glass lens should be used as an eyeglass to throw the image back to the retina?

2. If the lens of the eye forms an image too far back, what kind of lens should be used for an eyeglass?

3. If you wished to project a beam of light nearly parallel by means of a lens, say a beam like the beam of a searchlight, what would you do? At what distance from the lens would you place the source of light?

Materials Required.—A concave lens and two convex lenses (curvature of concave lens should be less than that of one of the convex lenses), meter stick with support and clamps, candle or other source of light, cardboard.

EXPERIMENT 145

MAGNIFYING POWER OF A LENS

How can a convex lens be made to aid the eye in seeing small objects?

What to do?

(*a*) Set up a ring stand as in Fig. 125. In the card on the upper ring at *A* cut a circular hole a little smaller than the lens. In a card, which is later to be placed at *B*, cut a hole 1 cm. square. This hole must be exactly square and the edges smooth. Place at *C* a sheet of cross-section paper which is ruled in centimeters and millimeters.

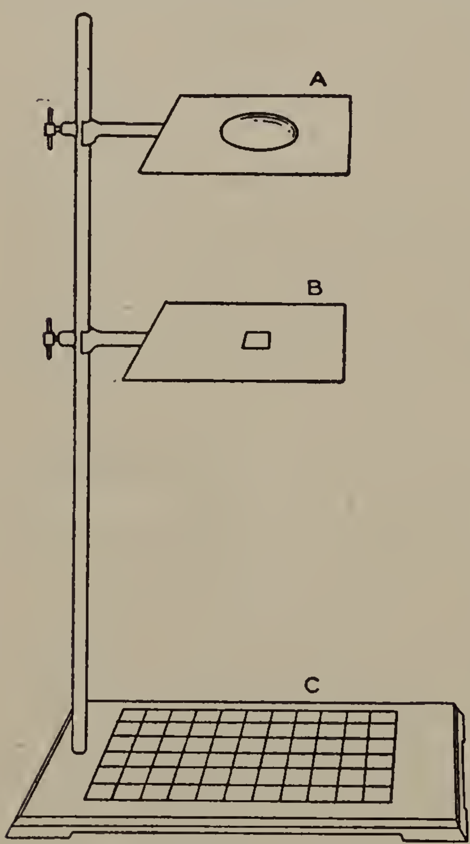


FIG. 125.

(*b*) Place card *A* on the ring at a distance of 25 cm. (10 in.) from *C*. If your eye is normal, this is the least distance at which you can see an object distinctly without straining the eye. Place a sheet of printed matter at *C* and with the eye at *A* see if you can read easily.

(*c*) Place a convex lens on *A* and bring the printed matter nearer to your eye as you look through the lens. Find the position of the printed matter at which you can see it most distinctly with the aid of the lens. Remove the printed matter and put the card with the square hole in

its place. This card (B) is now in the position for most distinct vision through the lens while C is in position for most distinct vision with the eye alone.

Without using the lens look through the hole in B, your eye being at A, and without moving the eye note how many square centimeters you can see on card C. A square centimeter at B, then, appears as large as how many square centimeters at C? If an object were moved from C to B it would appear to be enlarged how many times in diameter? How many times in area?

This magnification could be accomplished by the eye alone by simply moving the object nearer to the eye if the eye lens were able to adjust itself for so short a distance. The use of the glass lens is simply to aid the eye lens in focusing the image on the retina. If the glass lens were not used and the eye were at A and the object at B would the image in the eye be behind or in front of the retina?

(*d*) Measure the distance AB. The ratio of AC to AB should be the same as the ratio of diameters found in the preceding test. This ratio is the magnifying power of the lens.

Questions.—1. If a convex lens enables you to see an object distinctly when held 1 in. from the eye, what is its magnifying power?

2. If you are using a lens which has a magnifying power of 20 diameters at what distance from the eye will you hold the object?

Materials Required.—Convex lens; iron ring stand; cardboard; cross-section paper; centimeter ruler or meter stick.

EXPERIMENT 146

THE COMPOUND MICROSCOPE AND THE TELESCOPE

What to do:

(*a*) Set up a meter-stick support (Fig. 126) with a candle or other luminous object at *A*, a convex lens on a clamp at *B*, and a cardboard at *C*.

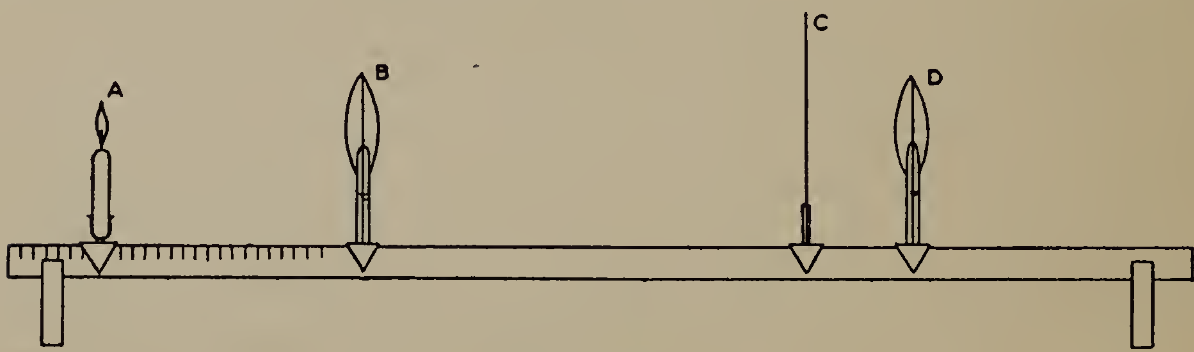


FIG. 126.

(*b*) Adjust the distance of the lens and the cardboard until a distinct image of the candle larger than the candle is seen on the card. Find the ratio of the distance *BC* to *AB*. This ratio is also the ratio of the diameter of the image to the diameter of the candle.

(*c*) Place another convex lens at *D*, remove the card at *C* leaving the clamp to mark the position of *C*. Look through the lens *D* with the eye close to the lens. Move *D* back and forth until you can see clearly the inverted image of the candle. You are now using the lens *D* as a simple microscope to look at the real image at *C*. You are looking at that image as truly as if it were a real object. Measure the distance from your eye to the image, that is, from *D* to the place where card *C* was before you

removed it. By the method learned in the experiment on the simple microscope find how many diameters the image is magnified by the lens at *D*. Proceed just as if there were a real object at *C*.

This combination of lenses represents a compound microscope. The lens at *B* next to the object is the objective, the lens at *D* next to the eye is the eyepiece.

The inverted image at *C* can be seen by the eye alone without the aid of the lens. Try it.

(*d*) Find the magnifying power of your microscope by multiplying the magnifying power of the objective by the magnifying power of the eyepiece.

(*e*) To illustrate the principle of the astronomical telescope move the candle farther from *B* so that the image will be smaller than the candle and adjust *C* to get a distinct image. Look through the lens at *D* as before and adjust the lens for distinct vision. Note that in the telescope all the magnifying is done by the eyepiece while in the microscope the objective also magnifies.

In the astronomical telescope the image is inverted as it is in this experiment but in the terrestrial telescope a combination of lenses is used for the eyepiece which makes the image erect.

Materials Required.—Two convex lenses; candle or other luminous object; meter-stick supports with clamps; meter stick; cardboard.

EXPERIMENT 147

THE OPERA GLASS

What to do:

(*a*) Set up a meter-stick support having a candle or other luminous object at *A*, a convex lens at *B*, and a card at *C*. Adjust the distances until a distinct image is formed which is smaller than the candle (Fig. 127).

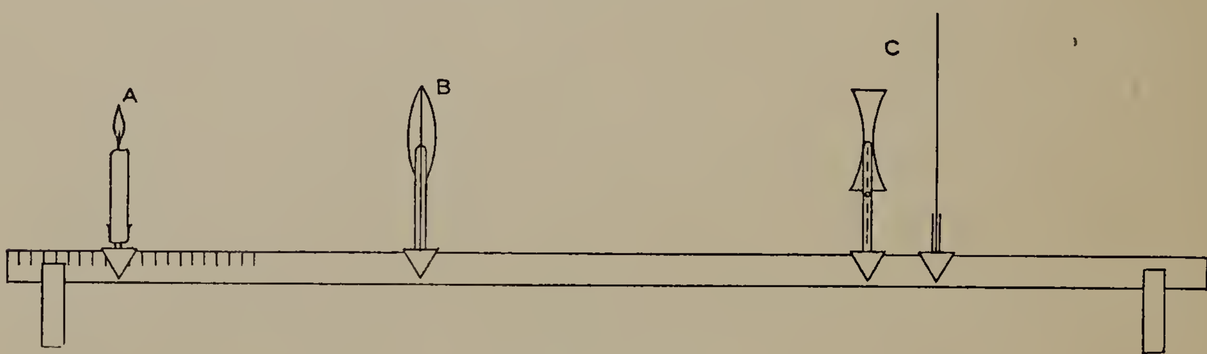


FIG. 127.

(*b*) Remove the card *C* and place a concave lens in the beam of light a little nearer to the candle than the place where card *C* was at first. Look through the concave lens toward the lens *B* holding the eye close to the lens. Move *B* back and forth until you see a distinct image. Why is the image not inverted?

This arrangement of lenses represents an opera glass. How does an opera glass differ from an astronomical telescope?

Materials Required.—A convex lens and a concave lens; meter stick with support and clamps; candle or other luminous object; cardboard.

EXPERIMENT 148

THE CAMERA

How are the principles of lenses applied in the photographic camera?

What to do:

(*a*) Remove the lens from the camera and by means of a beam of sunlight find its principal focus and its focal length.

Is the image ever nearer to the lens than its principal focus? Is it ever farther away than the principal focus?

(*b*) Replace the lens in the camera and focus on some distant object. Do not use the focusing scale but look at the image on the ground glass and move the ground glass by turning the focusing screw until the image is distinct. Now direct the lens toward some object in the room and focus the image. Do you have to move the ground glass farther from the lens or nearer to it than when it was focused on a distant object?

(*c*) Open the diaphragm to its full width, or if the camera has stops put in the largest stop. Focus on any well-lighted object. Now reduce the opening in the diaphragm or change to the smallest stop.

In which case is the image brighter? In which case is the image more distinct, that is, which gives the sharper focus, a small stop or a large stop? It will require careful examination of the image to answer the last question.

If the light were very strong, would you make the opening in the diaphragm large or small? If the light were

very weak, what size of opening would you use? For the most distinct image, what size of opening would you use?

(*d*) (Optional.) If time permits, an exposure may be made and a plate developed. Instructions for the latter operation cannot be given here but must be supplied by the instructor.

Materials Required.—A camera.

EXPERIMENT 149

THE POSTCARD PROJECTOR

Introductory Discussion.—The apparatus for a simple postcard projector costs very little and can be made in a few minutes by any boy who is handy with tools. Make a box about 1 ft. high with a base about 15 in. square. A soap box or a cracker box can be cut to the right size. In one side cut two circular holes as shown in Fig. 128. One

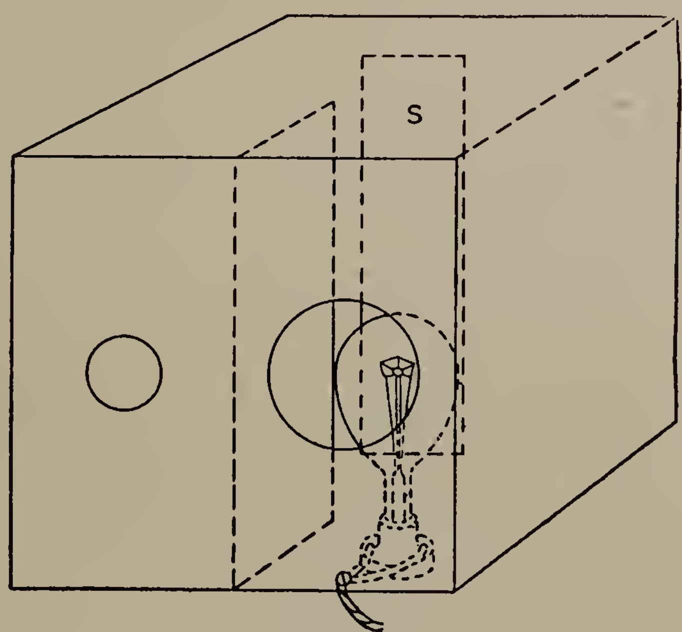


FIG. 128.

hole should be about 3 in. in diameter and the other about 8 in. in diameter. Set up a movable block of wood (*S* in Fig. 128) to which a postcard can be attached. Put a thin board partition about 3 in. wide between the two holes. Put a porcelain base socket in the box. Leave the socket movable and insert in it a 100-watt gas-filled (nitrogen) incandescent lamp. Just outside the box

close to the large hole place a common wall-lamp reflector. The lamp should be supported in such a position that the filament is as close as possible to the reflector near its center. The reflector should be placed so that it throws a strong beam of light on the postcard at *S*. A parabolic reflector such as is used in automobile electric headlights gives better results but the wall-lamp reflector is satisfactory and less expensive.

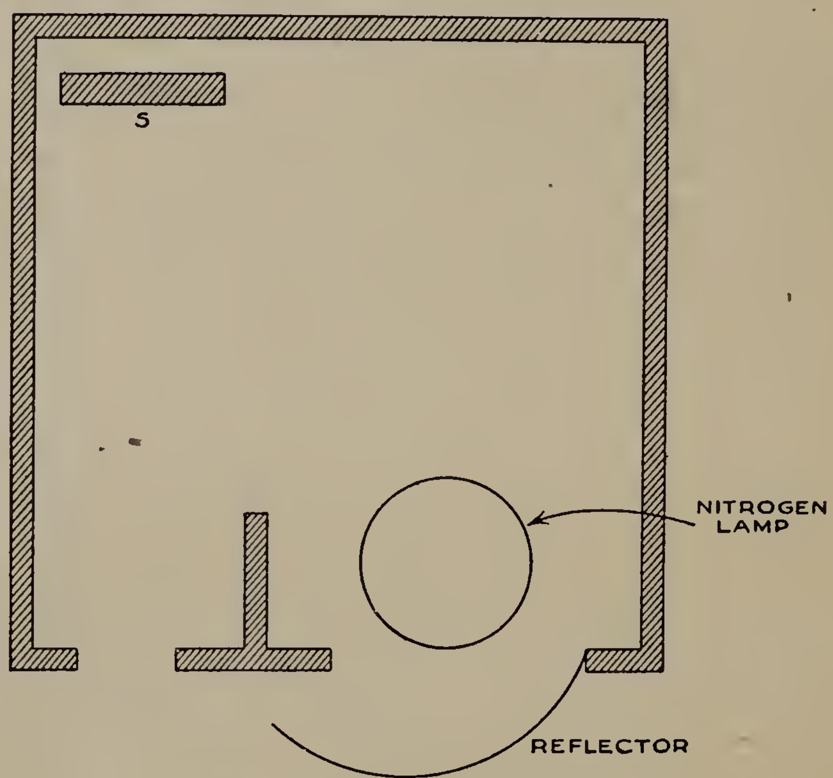


FIG. 129.

This apparatus is to be used also for experiments 151 and 152.

What to do:

(*a*) Having the postcard in position (inverted) at *S* and illuminated by a strong beam of light, hold a convex lens near the smaller opening in the box and project an image of the postcard on a white cardboard screen. Adjust the distances between *S* and the lens and between the screen and the lens until the image is very distinct.

(*b*) Move the screen farther from the box. Must the

lens now be moved nearer to the postcard or farther from it to make the image distinct? Try it. Give a reason for the answer that you discover to be the correct one referring to experiment 144.

(*c*) Make a drawing to show why the image is right side up when the postcard is inverted; also why the picture is reversed, that is, why the left side of the postcard appears as the right side of the image. If there is printed matter on the postcard it reads backward in the image (see Fig. 130).

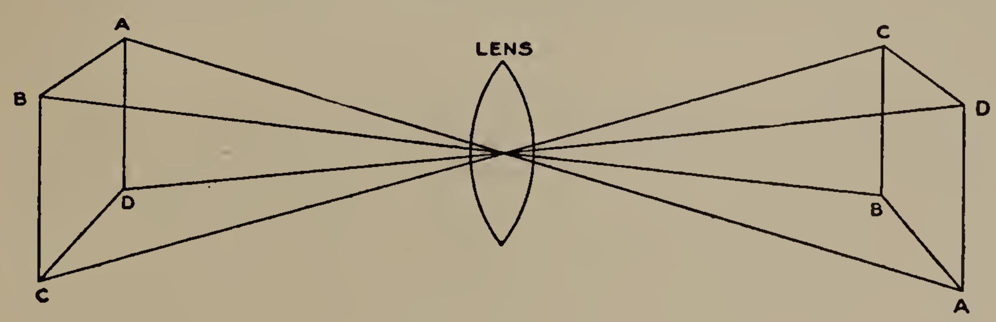


FIG. 130.

(*d*) Now place a plane mirror in the path of the light near the lens and forming an oblique angle with the beam. Move the screen to such a position that the mirror throws an image upon it.

The mirror does not invert the image but reverses it, that is, changes the right and left sides so that printed matter will read from left to right as it should. Make a drawing tracing the path of the light to show why this is so.

Materials Required.—Simple postcard projector apparatus as described above.

EXPERIMENT 150

A PRISM AND THE SPECTRUM

How is a beam of light bent by a prism?

How is white light separated into the spectrum colors?

What to do:

(*a*) Place a triangular prism on a sheet of note paper. The prism should stand on one end so that lines drawn around it on the paper will form a triangle (see Fig. 131).

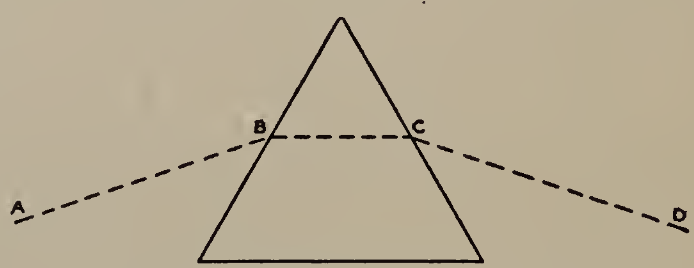


FIG. 131.

Place a pin in the paper at *B* in contact with the prism. Look through the prism at the pin. Where does the pin appear to be?

CAUTION.—You can see two images of the pin when looking through the prism. One of these is due to reflection; this is not the image to use in the following test. If you are not sure which image is caused by reflection you may draw lines representing the direction of light for both and then decide which image is caused by reflection and which by refraction.

(*b*) The light coming from the pin is bent by the prism. The next step is to find the direction of the light before it enters and after it leaves the prism. Set two pins between

your eye and the prism so that they are in line with the image of *B* seen through the prism. With a ruler draw a line joining these two pins and extend the line to the face of the prism. This line, *CD*, represents the direction of the light passing from the prism to your eye. Again looking along the line *CD* and through the prism set another pin farther from the prism and in line with *CD* and the image of *B*. Draw the line *AB* joining these two pins. This line represents the direction of the light passing from the pin *A* to the prism. After removing the prism join *B* and *C*. The line *BC* represents the light passing through the prism.

Is the light bent toward the thicker or the thinner part of the prism?

(*c*) Cut a slit as long as the prism and about 3 mm. wide in a piece of cardboard. Hold the prism in the sunlight with this slit on the side toward the sun. Let the light which passes through the prism fall upon a white cardboard or paper. Name the colors. Do not name them as you have learned them from a book but the colors you actually see. The white light is separated into colors because the light constituting the different colors is bent at different angles. Which color is bent most? Which is bent least? To make sure of your answers to the last two questions hold the cardboard in place and remove the prism. You can then see the position of the beam of light as it passes directly through the slit and thus find out in which direction the prism bends the beam.

Look through the prism toward a candle flame or other artificial light. Why does the light have a band of colors around it?

Materials Required.—60° prism; pins; cardboard.

EXPERIMENT 151

ABSORPTION OF LIGHT AND APPLICATION TO WALL PAPER

What to do:

(*a*) Procure a postcard projector apparatus (see experiment 149). Arrange the apparatus as in experiment 149 except that the lens is not to be used.

(*b*) Put a piece of white paper into the place for the postcard and let the light reflected from the paper fall on a book held near the opening in the box. Find a position for the book such that it is easy to read by the light reflected from the paper.

Caution.—No direct light from the lamp must be allowed to fall upon the book. To prevent this a cardboard screen should be placed between the book and the lamp.

(*c*) Put the larger samples of wall paper of different colors in place of the white paper in the box using the samples in succession and letting the light from each fall upon the book. Try reading with the book in the same place as it was when you used the white paper.

Paste the small samples of the wall paper into your notebook in the order in which they absorb light placing first the one that absorbs least light, that is, the one that reflects the most light.

Does the kind of wall paper or other wall decoration have any effect upon the illumination of a room?

Materials Required.—Postcard projector apparatus; samples of wall paper (several colors) about 6 in. square; other samples of the same paper about 1 in. square.

EXPERIMENT 152

COLORS OF OBJECTS UNDER VARIOUS LIGHTS

Why is it impossible to match colors by gas or electric light so that they appear the same by daylight?

What to do:

(*a*) Set up the postcard projector apparatus having the lamp reflector outside the box so that the beam of light can be thrown through a color screen upon a postcard (Fig. 132). The color screens may be gelatin films or colored glass.

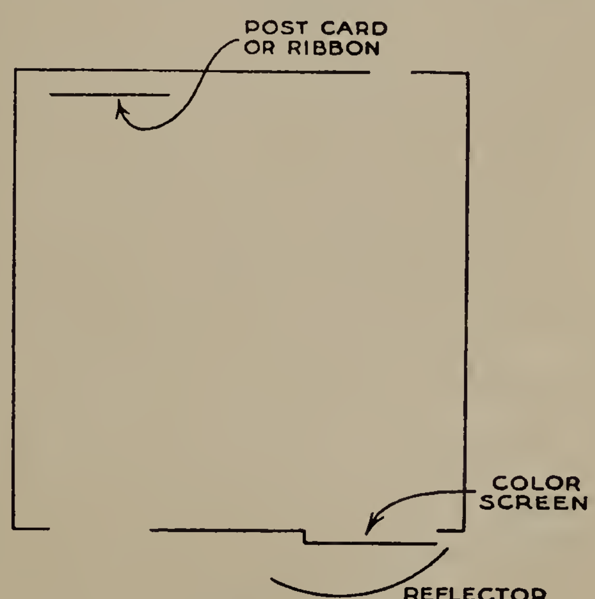


Fig. 132.

(*b*) Place a colored postcard in position and use the different color screens in succession. At least four color screens, blue, green, yellow, and red, should be used. Do the colors on the postcard appear the same in the different colored lights?

(*c*) Use different colored ribbons in place of the postcard. What do you observe in regard to the colors of the ribbons?

Answer the question asked at the beginning of the experiment bearing in mind that gas and electric light do not contain quite the same colors as sunlight.

Materials Required.—Postcard projector apparatus; colored postcard; colored ribbons; color screens.

EXPERIMENT 153

PHOTOGRAPHIC ACTION OF DIFFERENT COLORED LIGHTS

What to do:

(*a*) Secure a strip of cardboard about 3 in. wide and 8 in. long. Cut into the strip five holes about 1½ in. in diameter, spacing them evenly. Fasten over these holes pieces of colored gelatine or glass, starting with the left-hand hole and having the following colors in the order given: (1) red, (2) orange, (3) yellow, (4) green, (5) blue.

(*b*) Having made the *color strip* as indicated in paragraph (*a*) place it upon a piece of blueprint paper which you have marked in such a way that you can tell left from right, and so that the sensitive side of the paper is next to the colors. Now expose to strong sunlight so that the light passes through the colors for about 2 minutes. Remove the blueprint paper and wash it immediately in cold water. Allow it to wash for 5 minutes and then hang it up to dry, but *not* in the sun.

(*c*) Blueprint paper is peculiar in that the portion which has received the greatest amount of light will turn blue after washing while the portions least affected or not acted upon will remain or become white. Bearing this in mind, examine your print of the color strip and then answer the following:

Are all of the spots of the same intensity?

Which of them is brightest?

Since all of the colors were subjected to the same light

at the same time, what has become of the light in passing through the different colors?

Is this absorption quality of any particular commercial value? Name several.

Materials Required.—Piece of cardboard 3 by 8 in., having five holes in it about the size of a half-dollar, covered with the following colors: red, orange, yellow, green and blue respectively; a piece of blueprint paper the size of the color strip.

APPENDIX

TABLE I.—HANDY REFERENCES

$\pi = 3.1416$ $\qquad \pi^2 = 9.8696$ $\qquad \pi/4 = 0.7854$

$\sqrt{2} = 1.41428$ $\qquad \sqrt{3} = 1.73205$ $\qquad \sqrt{5} = 2.23607$

Circle circumference $= 2\pi r = \pi D$.

Circle area $= \pi r^2 = \pi D^2/4$.

Tube end area $= \pi(R^2 - r^2) = \dfrac{\pi}{4}(D^2 - d^2)$.

Sphere surface $= 4\pi R^2 = \pi D^2$.

Sphere volume $= \dfrac{4\pi R^3}{3} = \dfrac{\pi D^3}{6}$.

Right cone surface $= \pi R(\sqrt{H^2 + R^2} + R) =$

$$\frac{\pi D}{2}\left(\sqrt{H^2 + \frac{D^2}{4}} + \frac{D}{2}\right)$$

Right cone volume $= \dfrac{\pi R^2 H}{3} = \dfrac{\pi D^2 H}{12}$

Right cylinder surface $= 2\pi R(R + H) = \pi D(D/2 + H)$.

Right cylinder volume $= \pi R^2 H = \dfrac{\pi D^2 H}{4}$.

Cone volume $= \dfrac{\pi R^2 H}{3}$.

Cone frustum volume $= \dfrac{H}{3}(B + b + \sqrt{Bb}) = \dfrac{\pi H}{3}(R^2 + r^2 + \sqrt{R^2 r^2})$.

Cone convex surface = circumference of base $\times$ half slant height.

TABLE 2.—HOUSEHOLD VOLUMES AND WEIGHTS

Volumes

4 t(teaspoonfuls)	= 1 T(tablespoonful)
4 T	= ½ gill = ¼ cupful = ½ pt.
1 kitchen cupful	= ½ pt.
4 cups flour	= 1 qt. = 1 lb.

Weights

1 T liquid	= ½ oz.
1 T butter	= 1 oz.
Butter size of egg	= 2 oz.
Pint of liquid	= 1 lb.
1 heaping qt. sifted flour	= 1 lb.
4 cups flour	= 1 lb.
3 cups corn meal	= 1 lb.
1 pt. butter	= 1 lb.
10 eggs	= 1 lb.
1 pt. granulated sugar	= 1 lb.
2½ cups powdered sugar	= 1 lb.

TABLE 3.—THE GREEK ALPHABET

Name	Large	Small	Commonly used to designate
alpha......	A	α	Angles, coëfficients
beta.......	B	β	Angles, coefficients
gamma	Γ	γ	Specific gravity
delta	Δ	δ	Density, variation
epsilon.....	E	ϵ	Base of hyperbolic logarithms
zeta.......	Z	ζ	Coördinates, coefficients
eta........	H	η	Hysteresis coefficient, efficiency
theta......	Θ	θ	Angular displacement, time constant
iota	I	ι	
kappa	K	κ	Dielectric constant, susceptibility
lambda	Λ	λ	Conductivity
mu........	M	μ	Permeability
nu	N	ν	Reluctivity
xi.........	Ξ	ξ	Output coefficient
omicron ...	O	o	
pi.........	Π	π	Circumference ÷ diameter
rho........	P	ρ	Resistivity
sigma......	Σ	σ	Summation; leakage coefficient
tau........	T	τ	Time-phase displacement, time constant
upsilon	Υ	υ	
phi........	Φ	ϕ	Flux
chi........	X	χ	
psi	Ψ	ψ	Angular velocity in time
omega.....	Ω	ω	Angular velocity in space

Taken from Standard Hand Book.

Table 4.—Decimals of an Inch for Each Sixty-fourth

32nds	64ths	Decimal	Fraction	32nds	64ths	Decimal	Fraction
	1	0.0156			33	0.5156	
1	2	0.0313		17	34	0.5313	
	3	0.0469			35	0.5469	
2	4	0.0625	1/16	18	36	0.5625	9/16
	5	0.0781			37	0.5781	
3	6	0.0938		19	38	0.5938	
	7	0.1094			39	0.6094	
4	8	0.1250	1/8	20	40	0.6250	5/8
	9	0.1406			41	0.6406	
5	10	0.1563		21	42	0.6563	
	11	0.1719			43	0.6719	
6	12	0.1875	3/16	22	44	0.6875	11/16
	13	0.2031			45	0.7031	
7	14	0.2188		23	46	0.7188	
	15	0.2344			47	0.7344	
8	16	0.2500	1/4	24	48	0.7500	3/4
	17	0.2656			49	0.7656	
9	18	0.2813		25	50	0.7813	
	19	0.2969			51	0.7969	
10	20	0.3125	5/16	26	52	0.8125	13/16
	21	0.3281			53	0.8281	
11	22	0.3438		27	54	0.8438	
	23	0.3594			55	0.8594	
12	24	0.3750	3/8	28	56	0.8750	7/8
	25	0.3906			57	0.8906	
13	26	0.4063		29	58	0.9063	
	27	0.4219			59	0.9219	
14	28	0.4375	7/16	30	60	0.9375	15/16
	29	0.4531			61	0.9531	
15	30	0.4688		31	62	0.9688	
	31	0.4844			63	0.9844	
16	32	0.5000	1/2	32	64	1.0000	16/16

TABLE 5.—FUNCTIONS OF ANGLES

Angle	Sine	Cosine	Tangent	Angle	Sine	Cosine	Tangent
0	0.000	1.000	0.000	45	0.707	0.707	1.000
1	0.017	1.000	0.017	46	0.719	0.695	1.036
2	0.035	0.999	0.035	47	0.731	0.682	1.072
3	0.052	0.999	0.052	48	0.743	0.669	1.111
4	0.070	0.998	0.070	49	0.755	0.656	1.150
5	0.087	0.996	0.087	50	0.766	0.643	1.192
6	0.105	0.995	0.105	51	0.777	0.629	1.235
7	0.122	0.993	0.123	52	0.788	0.616	1.280
8	0.139	0.990	0.140	53	0.799	0.602	1.327
9	0.156	0.988	0.158	54	0.809	0.588	1.376
10	0.174	0.985	0.176	55	0.819	0.574	1.428
11	0.191	0.982	0.194	56	0.829	0.559	1.483
12	0.208	0.978	0.213	57	0.839	0.545	1.540
13	0.225	0.974	0.231	58	0.848	0.530	1.600
14	0.242	0.970	0.249	59	0.857	0.515	1.664
15	0.259	0.966	0.268	60	0.866	0.500	1.732
16	0.276	0.961	0.287	61	0.875	0.485	1.804
17	0.292	0.956	0.306	62	0.883	0.469	1.881
18	0.309	0.951	0.325	63	0.891	0.454	1.963
19	0.326	0.946	0.344	64	0.899	0.438	2.050
20	0.342	0.940	0.364	65	0.906	0.423	2.145
21	0.358	0.934	0.384	66	0.914	0.407	2.246
22	0.375	0.927	0.404	67	0.921	0.391	2.356
23	0.391	0.921	0.414	68	0.927	0.375	2.475
24	0.407	0.914	0.445	69	0.934	0.358	2.605
25	0.423	0.906	0.466	70	0.940	0.342	2.747
26	0.438	0.899	0.488	71	0.946	0.326	2.904
27	0.454	0.891	0.510	72	0.951	0.309	3.078
28	0.469	0.883	0.532	73	0.956	0.292	3.271
29	0.485	0.875	0.554	74	0.961	0.276	3.487
30	0.500	0.866	0.577	75	0.966	0.259	3.732
31	0.515	0.857	0.601	76	0.970	0.242	4.011
32	0.530	0.848	0.625	77	0.974	0.225	4.331
33	0.545	0.839	0.649	78	0.978	0.208	4.705
34	0.559	0.829	0.675	79	0.982	0.191	5.145

TABLE 5.—FUNCTIONS OF ANGLES—*Continued*

Angle	Sine	Cosine	Tangent	Angle	Sine	Cosine	Tangent
35	0.574	0.819	0.700	80	0.985	0.174	5.671
36	0.588	0.809	0.727	81	0.988	0.156	6.314
37	0.602	0.799	0.754	82	0.990	0.139	7.115
38	0.616	0.788	0.781	83	0.993	0.122	8.144
39	0.629	0.777	0.810	84	0.995	0.105	9.514
40	0.643	0.766	0.839	85	0.996	0.087	11.430
41	0.656	0.755	0.869	86	0.998	0.070	14.300
42	0.669	0.743	0.900	87	0.999	0.052	19.080
43	0.682	0.731	0.933	88	0.999	0.035	28.640
44	0.695	0.719	0.966	89	1.000	0.017	57.290
45	0.707	0.707	1.000	90	1.000	0.000	∞

TABLE 6.—CHARACTERISTICS OF COPPER CONDUCTORS. (B & S Gauge)

	Diameter, mils	Circular mils	Per 1,000 ft.		Allowed current	
			Ohms	Pounds	Rubber-covered	Weather-proof
American Wire or Brown & Sharpe Gauge	1,414.00	2,000,000.0	0.00519	6,044.00	1,050	1,670
	1,323.00	1,750,000.0	0.00593	5,289.00		
	1,225.00	1,500,000.0	0.00692	4,533.00	850	1,360
	1,118.00	1,250,000.0	0.00830	3,778.00		
	1,000.00	1,000,000.0	0.01038	3,022.00	650	1,000
	974.70	950,000.0	0.01093	2,871.00		
	948.70	900,000.0	0.01153	2,720.00	600	920
	922.00	850,000.0	0.01221	2,569.00		
	894.40	800,000.0	0.01298	2,418.00	550	840
	866.00	750.000,0	0.01384	2,266.00		
	836.70	700,000.0	0.01483	2,115.00	500	760
	806.20	650,000.0	0.01597	1,964.00		
	774.60	600,000.0	0.01730	1,813.00	450	680
	741.60	550,000.0	0.01887	1,662.00		
	707.10	500,000.0	0.02076	1,511.00	390	590
	670.80	450,000.0	0.02307	1,360.00		
	632.50	400,000.0	0.02595	1,209.00	330	500
	591.60	350,000.0	0.02966	1,058.00		
	547.70	300,000.0	0.03460	906.50	270	400

Table 6.—Characteristics of Copper Conductors. (B & S Gauge)
Continued

	Diameter, mils	Circular mils	Per 1,000 ft.		Allowed current	
			Ohms	Pounds	Rubber-covered	Weather-proof
	500.00	250,000.0	0.04152	755.50		
	474.30	225,000.0	0.04614	680.00		
0000	460.00	211,600.0	0.04906	639.33	210	312
000	409.64	167,805.0	0.06186	507.01	177	262
00	364.80	133,079.0	0.07801	402.09	150	220
0	324.95	105,592.0	0.09831	319.04	127	195
1	289.30	83,694.0	0.12404	252.88	107	156
2	257.63	66,373.0	0.15640	200.54	90	131
3	229.42	52,634.0	0.19723	159.03	76	110
4	204.31	41,742.0	0.24869	126.12	65	92
5	181.94	33,102.0	0.31361	100.01	54	77
6	162.02	26,251.0	0.39546	79.32	46	75
7	144.28	20,816.0	0.49871	62.90	40	55
8	128.49	16,509.0	0.62881	49.88	33	46
9	114.43	13,094.0	0.79281	39.56	27	38
10	101.89	10,381.0	1.00000	31.37	24	32
12	80.81	6,529.9	1.58980	19.73	17	23
14	64.08	4,106.8	2.59080	12.41	12	16
16	50.82	2,582.9	4.01910	7.81	6	8
18	40.30	1,624.3	6.39110	4.91	3	5
19	35.39	1,288.1	8.28890	3.89		
20	31.96	1,021.5	10.16300	3.09		
22	25.35	642.7	16.15200	1.94		
24	20.10	404.0	25.69500	1.22		
28	12.64	159.8	64.96600	0.48		
32	7.95	63.2	164.26000	0.19		
36	5.00	25.0	415.24000	0.08		
40	3.14	9.9	1,049.70000	0.03		

TABLE 7.—HEAT-CONDUCTING POWER OF METALS. (Calvert and Johnson)

Silver	1,000
Gold	981
Gold with 1 per cent. silver	840
Copper (rolled)	845
Copper (cast)	811
Mercury	677
Mercury with 1.25 per cent. tin	412
Aluminum	665
Zinc (cast vertically)	628
Zinc (cast horizontally)	608
Zinc (rolled)	641
Cadmium	577
Wrought iron	436
Tin	422
Steel	397
Platinum	380
Sodium	365
Cast iron	359
Lead	287
Antimony (cast horizontally)	215
Antimony (cast vertically)	192
Bismuth	61

NOTE.—This table also applies to conductors of electricity.

TABLE 8.—DENSITY OF SOLIDS. (Metals)

Aluminum	2.56 – 2.80	Lead	11.00–11.36
Antimony	6.62 – 6.72	Magnesium	1.69– 1.75
Arsenic	4.72 – 5.73	Manganese	6.86– 8.03
Babbit (white metal)	7.31	Nickel	8.30– 8.93
Barium	3.75 – 4.00	Phosphorus (yellow)	1.82
Bismuth	9.75 – 9.90	Platinum	21.48
Brass (cast)	8.30+	Potassium	0.87
Brass (rolled)	8.44	Silicon	2.00– 2.49
Bronze	8.70	Silver	10.40–10.57
Calcium	1.54 – 1.58	Silver (German)	8.62
Calcium chloride	2.23	Sodium	0.97
Carbon	1.75 – 3.56	Strontium	2.54
Chromium	6.92	Sulphur	1.92– 2.07
Cobalt	8.72	Tantalum	12.79
Copper	8.91 – 8.96	Tellurium	6.01– 6.27
Gold (18 carat)	14.88	Thorium	11.00–11.23
Gold (pure)	19.26–19.34	Tin	5.85– 7.30
Iodine	4.95	Tungsten	18.77
Iron (cast)	7.10 – 7.60	Uranium	18.69
Iron (steel)	7.79	Zinc (cast)	6.86
Iron (wrought)	7.80	Zinc (rolled)	7.20

TABLE 9.—DENSITY OF SOLIDS. (Woods, from Kent)

Alder	0.680	Hornbeam	0.760
Apple	0.760	Juniper	0.560
Ash	0.720	Larch	0.560
Bamboo	0.350	Lignum vitæ	1.000
Beech	0.730	Linden	0.604
Birch	0.650	Locust	0.728
Box	1.120	Mahogany	0.810
Cedar	0.620	Maple	0.680
Cherry	0.660	Mulberry	0.730
Chestnut	0.560	Oak (live)	0.960–1.260
Cork	0.240	Oak (white)	0.690–0.860
Cypress	0.530	Oak (red)	0.730–0.750
Dogwood	0.760	Pine (white)	0.350–0.600
Ebony	1.230	Pine (yellow)	0.460–0.780
Elm	0.610	Poplar	0.380–0.580
Fir	0.590	Spruce	0.450
Gum	0.920	Sycamore	0.600
Hackmatack	0.590	Teak	0.660–0.980
Hemlock	0.380	Walnut	0.500–0.670
Hickory	0.770	Willow	0.490–0.590
Holly	0.760		

TABLE 10.—DENSITY OF STONES, BRICK, CEMENT. (Kent)

Agate	2.615	Gravel	1.600–1.920
Asphaltum	1.390	Gypsum	2.080–2.400
Brick (soft)	1.600	Hornblende	3.200–3.520
Brick (common)	1.790	Lime (quick)	0.800–0.880
Brick (hard)	2.000	Limestone	2.720–3.200
Brick (pressed)	2.160	Magnesia (carbonate)	2.400
Brick (fire)	2.250–2.400	Marble	2.560–2.880
Brickwork in mortor	1.600	Masonry (dry rubble)	2.240–2.560
Brickwork in cement	1.790	Masonry (dressed)	2.240–2.880
Cement (Rosendale)	0.960	Mortar	1.440–1.600
Cement (Portland)	1.250	Pitch	1.150
Clay	1.920–2.400	Plaster of Paris	1.180–1.280
Concrete	1.920–2.240	Porcelain	2.380
Diamond	3.530	Quartz	2.640
Earth (loose)	1.150–1.280	Sand	1.440–1.760
Earth (rammed)	1.440–1.760	Sandstone	2.240–2.400
Emery	4.000	Slate	2.720–2.880
Glass (crown)	2.520	Soapstone	2.650–2.800
Glass (flint)	3.000–3.600	Trap	2.720–3.400
Glass (green)	2.640	Tile	1.760–1.920
Granite	2.560-2.720		

TABLE 11.—DENSITY OF LIQUIDS

Acids:		Oils:	
Acetic at 15°C......	1.0530	Castor.........	0.9700
Hydrochloric.......	1.2200	Cottonseed.....	0.9260
Nitric.............	1.5200	Linseed........	0.9400
Sulphuric..........	1.8400	Olive..........	0.9200
Alcohol:		Palm..........	0.9700
Absolute at 15°C....	0.7937	Rape..........	0.9200
Amyl at 15°C.......	0.8090	Whale.........	0.9200
Common...........	0.8125	Petroleum	0.7800–0.8800
95 per cent.........	0.8080–0.8150	Naphtha.......	0.7480
Bromine............	2.9700	Benzine........	0.8900
Carbon bisulphide....	1.2700	Gasoline.......	0.6860–0.7070
Chloroform..........	1.4990	Kerosene.......	0.7780–0.8040
Ether...............	.07200	Turpentine.....	0.8720
Ether (Squibbs').....	0.7360	Tar...........	1.0200
Glycerin............	1.2600	Vinegar........	1.0800
Mercury............	13.5960	Water:	
Milk (cows) at 0°C...	1.0300	Sea at 0°C.....	1.0260
Molasses...........	1.4260	Lake at 0°C....	0.9990
		Lake at 4.07°C..	1.0000
		Lake at 100°C..	0.9580

TABLE 12.—DENSITY OF GASES

Air	1.0000	Hydrogen	0.0696
Acetylene	0.8980	Methane (marsh gas)	0.5530
Ammonia	0.5889	Nitrogen	0.9701
Carbon monoxide	0.9670	Oxygen	1.1050
Carbon dioxide	1.5200	Water vapor	0.6218
Chlorine	2.4900		

TABLE 13.—VEGETABLE COMPOUNDS AND OTHER MATERIALS

Alum	1.724	Graphite	2.500
Amber	1.078	Gunpowder	2.030
Beeswax	0.964	Gutta-percha	0.970
Bone	1.900	Human body	1.070
Butter	0.942	Ice	0.918
Canada balsam	1.070	Iceland spar	2.700
Camphor	0.988	Ivory	1.920
Chalk	1.800–2.800	Paraffin	0.824–0.940
Coal (hard or anthracite)	1.260–1.800	Rock salt	2.257
Coal (soft or bituminous)	1.270–1.423	Sealing wax	1.500–2.200
Feldspar	2.600	Sugar cane	1.593
Galena	7.580		

TABLE 14.—EQUIVALENTS OF UNITS OF LENGTH. (Sloane)

	Millimeter	Centimeter	Meter	Kilometer	Mil	Inch	Foot	Yard	Statute mile	Geographical mile
Millimeter	1	0.01	0.001	0.000001	39.37079	0.039371	0.003281	0.0010936	0.0000006	0.0000007
Centimeter	10	1	0.1	0.00001	393.7079	0.3937079	0.032809	0.010936	0.000006	0.000007
Meter	1,000	100	1	0.001	39,370.79	39.37079	3.28090	1.09363	0.000621	0.000716
Kilometer	1,000,000	100,000	1,000	1		39,370.79	3,280.899	1,093.633	0.621382	0.716330
Mil	0.025399	0.0025399	0.0000254		1	0.001	0.000083	0.000028		
Inch	25.3994	2.53994	0.025399	0.0000254	1,000	1	0.083333	0.027777	0.0000158	0.000015
Foot	304.7945	30.47945	0.304795	0.0003048	12,000	12	1	0.333333	0.000189	0.000164
Yard	914.3835	91.43835	0.914384	0.0009144	36,000	36	3	1	0.000568	0.000493
Statute mile		160,931.4	1,609.314	1.609314		63,360	5,280	1,760	1	0.868382
Geographical mile		185,329	1,853.29	1.85329		72,963.2	6,080.27	2,026.76	1.1516	1

TABLE 15.—EQUIVALENTS OF UNITS OF AREA. (Sloane)

	Square millimeter	Square centimeter	Circular mil	Square mil	Square inch	Square foot
Square millimeter	1	0.10	1973.6	1550.1	0.00155	0.0000108
Square centimeter	100	1	197.361	155.007	0.155007	0.001076
Circular mil	0.000507	0.0000051	1	0.78540	0.0000008	
Square mil	0.000645	0.0000065	1.2733	1	0.000001	
Square inch	645.132	6.451	1,273,238	1,000,000	1	0.006944
Square foot	92,898.9	928.989			144	1

TABLE 16.—EQUIVALENTS OF UNITS OF VOLUME. (Sloane)

	Cubic inch	Fluid ounce	Gallon	Cubic foot	Cubic yard	Cubic centimeter	Liter	Cubic meter
Cubic inch	1	0.554112	0.004329	0.000578		16.3862	0.016386	
Fluid ounce	1.80469	1	0.007812	0.001044		29.5720	0.029572	
Gallon	231	128	1	0.133681	0.00495	3,785.21	3.78521	0.003785
Cubic foot	1,728	957.506	7.48052	1	0.037037	28,315.3	28.3153	0.028315
Cubic yard	46.656	25,852.6	201.974	27	1	764,505	764.505	0.764505
Cubic centimeter	0.061027	0.033816	0.000264	0.000035		1	0.001	0.000001
Liter	61.027	33.8160	0.264189	0.035317		1,000	1	0.001
Cubic meter	61,027	33,816	264.189	35.3169	1.3080		1,000	1

TABLE 17.—EQUIVALENTS OF UNITS OF WEIGHT. (Sloane)

	Grain	Pound avoirdupois	Ton	Milligram	Gram	Kilogram
Grain	1	0.000143		64.799	0.064799	0.000065
Pound avoirdupois	7,000	1	0.000447		453.593	0.453593
Ton		2,000	1			907.186
Milligram	0.015432	0.000002		1	0.001	0.000001
Gram	15.4323	0.02205		1,000	1	0.001
Kilogram	15,432.3	2.20462	0.001102	1,000,000	1,000	1

TABLE 18.—EQUIVALENTS OF UNITS OF WORK AND ENERGY. (From Tower, Smith and Turton)

	Erg	Gram-centimeter	Kilogram-meter	Foot-pound	Gram-calorie	Kilogram-calorie	British thermal unit	Watt	Horse-power-second
Erg.........	1	0.00102	102×10^{-10}	7.37×10^{-10}	2.387×10^{-10}	238.7×10^{-15}	947.7×10^{-15}	1×10^{-7}	134×10^{-12}
Gram-centimeter .	981	1	1×10^{-5}	7.23×10^{-5}	2.342×10^{-5}	2.342×10^{-10}	9.297×10^{-10}	9.81×10^{-5}	$1{,}315\times10^{-10}$
Kilogram-meter......	981×10^{5}	10^{5}	1	7.23328	2.342	2.342×10^{-5}	0.009297	9.81	$1{,}315\times10^{-5}$
Foot-pound .	13,562,325	13,825	0.13825	1	0.32377	324×10^{-8}	0.0012853	1.356	0.001818
Gram-calorie	4.187×10^{7}	42,700	0.427	3.0886	1	0.001	0.00397	4.18876	0.0056
Kilogram-calorie......	4.187×10^{10}	4.27×10^{7}	427	3088.6	1,000	1	3.97	4,188.76	5.599
British thermal unit....	1.055×10^{10}	10,756,083	107.56	778	251.89	0.25189	1	1,055.107	1.4103
Watt.......	10^{7}	10,194	0.10194	0.73736	0.23873	23.873×10^{-5}	94.78×10^{-5}	1	0.00134
Horsepower-second	746×10^{7}	76.04×10^{5}	76.04	550	178.09	0.1780926	0.70706	746	1

TABLE 19.—COHESION OF SOME LIQUIDS. (Gay-Lussac)

A glass disk 118.366 mm. in diameter was used. The weight required to lift is given below.

Substance	Density	Temperature	Weight required to lift disk, in grams	Dynes
Alcohol............	0.8196	8.0°C.	31.08	30,458.40
Alcohol............	0.8596	10.0	32.87	32,212.60
Alcohol............	0.9415	8.0	37.15	36,407.00
Turpentine.........	0.8695	8.0	34.10	33,418.00
Water..............	1.0000	8.5	59.40	58,212.00

TABLE 20.—MEAN HEIGHT *b* OF BAROMETER AT ELEVATION *H* ABOVE THE SEA LEVEL. (Kohlrausch)

Temperature of Air at 10°C.

H Meters	*H* Feet	*b* Mm.	*b* Inches	*H* Meters	*H* Feet	*b* Mm.	*b* Inches
0	0	760	29.92	1,000	3,280	674	26.53
100	328	751	29.57	1,100	3,608	666	26.22
200	656	742	29.21	1,200	3,936	658	25.90
300	984	733	28.85	1,300	4,265	650	25.59
400	1,312	724	28.50	1,400	4,592	642	25.27
500	1,640	716	28.19	1,500	4,920	635	25.00
600	1,968	707	27.83	1,600	5,248	627	24.68
700	2,296	699	27.52	1,700	5,577	620	24.41
800	2,624	690	27.17	1,800	5,905	612	24.09
900	2,952	682	26.85	1,900	6,233	605	23.82
1,000	3,280	674	26.53	2,000	6,561	598	23.54

TABLE 21.—REDUCTION OF THE BAROMETER READING TO 0°C. ON ACCOUNT OF THE EXPANSION OF THE MERCURY AND OF THE SCALE. (Kohlrausch)

If t is the temperature at the time the height h of the mercury is taken, and β the coefficient of expansion of the metal of the scale, an amount equal to $(0.000181 - \beta)ht$ must be subtracted from h in order to obtain the reading reduced to 0°. The following results are thus obtained:

t	Observed height (h) in millimeters									
	680 mm.	690 mm.	700 mm.	710 mm.	720 mm.	730 mm.	740 mm.	750 mm.	760 mm.	770 mm.
1	0.11	0.11	0.11	0.12	0.12	0.12	0.12	0.12	0.12	0.12
2	0.22	0.22	0.23	0.23	0.23	0.24	0.24	0.24	0.25	0.25
3	0.33	0.34	0.34	0.35	0.35	0.35	0.36	0.36	0.37	0.37
4	0.44	0.45	0.45	0.46	0.47	0.47	0.48	0.49	0.49	0.50
5	0.55	0.56	0.57	0.58	0.58	0.59	0.60	0.61	0.62	0.62
6	0.66	0.67	0.68	0.69	0.70	0.71	0.72	0.73	0.74	0.75
7	0.77	0.78	0.79	0.81	0.82	0.83	0.84	0.85	0.86	0.87
8	0.88	0.89	0.91	0.92	0.93	0.95	0.96	0.97	0.98	0.99
9	0.99	1.01	1.02	1.04	1.05	1.06	1.08	1.09	1.11	1.12
10	1.10	1.12	1.13	1.15	1.17	1.18	1.20	1.22	1.23	1.25
11	1.21	1.23	1.25	1.27	1.28	1.30	1.32	1.34	1.35	1.37
12	1.32	1.34	1.36	1.38	1.40	1.42	1.44	1.46	1.48	1.50
13	1.43	1.45	1.47	1.50	1.52	1.54	1.56	1.58	1.60	1.62
14	1.54	1.56	1.59	1.61	1.63	1.66	1.68	1.70	1.72	1.75
15	1.65	1.68	1.70	1.73	1.75	1.77	1.80	1.82	1.85	1.87
16	1.76	1.79	1.81	1.84	1.87	1.89	1.92	1.94	1.97	2.00
17	1.87	1.90	1.93	1.96	1.98	2.01	2.04	2.07	2.09	2.12
18	1.98	2.01	2.04	2.07	2.10	2.13	2.16	2.19	2.22	2.25
19	2.09	2.12	2.15	2.19	2.22	2.25	2.28	2.31	2.34	2.37
20	2.20	2.24	2.27	2.30	2.33	2.37	2.40	2.43	2.46	2.49
21	2.31	2.35	2.38	2.42	2.45	2.48	2.52	2.55	2.59	2.62
22	2.42	2.46	2.49	2.53	2.57	2.60	2.64	2.67	2.71	2.74
23	2.53	2.57	2.61	2.65	2.68	2.72	2.76	2.79	2.83	2.87
24	2.64	2.68	2.72	2.76	2.80	2.84	2.88	2.92	2.95	2.99
25	2.75	2.79	2.84	2.88	2.92	2.96	3.00	3.04	3.08	3.12
26	2.86	2.91	2.95	2.99	3.03	3.07	3.12	3.16	3.20	3.24
27	2.97	3.02	3.06	3.11	3.15	3.19	3.24	3.28	3.32	3.37
28	3.08	3.13	3.18	3.22	3.27	3.31	3.36	3.40	3.45	3.49
29	3.19	3.24	3.29	3.34	3.38	3.43	3.48	3.52	3.57	3.62
30	3.30	3.35	3.40	3.45	3.50	3.55	3.60	3.65	3.69	3.74

TABLE 22.—BOILING TEMPERATURE t OF WATER AT BAROMETRIC PRESSURE b. (From Regnault's observations)

b	t	b	t	b	t	b	t	b	t
680	96.92°	700	97.72°	720	98.49°	740	99.26°	760	100.00°
81	.96	01	.75	21	.53	41	.29	61	.04
82	97.00	02	.79	22	.57	42	.33	62	.07
83	.04	03	.83	23	.61	43	.37	63	.11
84	.08	04	.87	24	.65	44	.41	64	.15
85	.12	05	.91	25	.69	45	.44	65	.18
86	.16	06	.95	26	.72	46	.48	66	.22
87	.20	07	97.99	27	.76	47	.52	67	.26
88	.24	08	98.03	28	.80	48	.56	68	.29
89	.28	09	.07	29	.84	49	.59	69	.33
90	.32	710	.11	730	.88	750	.63	770	.36
91	.36	11	.15	31	.92	51	.67	71	.40
92	.40	12	.19	32	.95	52	.70	72	.44
93	.44	13	.22	33	98.99	53	.74	73	.47
94	.48	14	.26	34	99.03	54	.78	74	.51
95	.52	15	.30	35	.07	55	.82	75	.55
96	.56	16	.34	36	.11	56	.85	76	.58
97	.60	17	.38	37	.14	57	.89	77	.62
98	.64	18	.42	38	.18	58	.93	78	.65
99	.68	19	.46	39	.22	59	.96	79	.69
700	97.72	720	98.49	740	99.26	760	100.00	80	100.72

TABLE 23.—MELTING POINTS AND HEATS OF LIQUEFACTION (LATENT HEATS) OF SOME SUBSTANCES. (Smithsonian, 1911)

	Melting point	Heat of liquefaction		Melting point	Heat of liquefaction
Aluminum....	658°C.		Mercury.....	−39°C.	2.82
Antimony.....	630		Nickel.......	1,450	4.64
Bismuth......	270	12.6	Palladium....	1,500	36.3
Bromine......	−7		Paraffin......	54	
Cadmium.....	321	13.6	Phosphorus...	44	5.0
Copper.......	1,083		Platinum.....	1,755	27.2
Glass.........	1,100		Selenium.....	217	
Ice...........	0	80.0	Silver........	961	24.7
Iodine........		11.7	Sodium......	97	
Iridium.......	2,275		Sulphur......	115	9.4
Iron.	1,200+		Tin..........	232	14.6
Lead.........	327	5.4	Zinc.........	419	28.1

TABLE 24.—BOILING POINTS AND HEATS OF VAPORIZATION (LATENT HEATS) OF SOME SUBSTANCES

	Boiling point	Heat of vaporization	Observer
Alcohol	77.9°C.	202.4	Andrews
Bisulphide of carbon	46.2	86.7	Andrews
Bromine	58.0	45.6	Andrews
Ether	34.9	90.4	Andrews
Mercury	350.0	62.0	Person
Turpentine	159.3	74.0	Brix
Water	100.0	535.9	Andrews

TABLE 25.—HUMIDITY TABLE

Pressure of aqueous vapor (p) in millimeters of mercury, and weight of water (w) in grams, contained in 1 cu. m. of air at the dew point (t).

	p mm.	w G.	t	p mm.	w G.	t	p mm.	w G.	t	p mm.	w G.
−10°	2.0	2.1	0°	4.6	4.9	10°	9.1	9.4	20°	17.4	17.2
−9	2.2	2.4	1	4.9	5.2	11	9.8	10.0	21	18.5	18.2
−8	2.4	2.7	2	5.3	5.6	12	10.4	10.6	22	19.7	19.3
−7	2.6	3.0	3	5.7	6.0	13	11.1	11.3	23	20.9	20.4
−6	2.8	3.2	4	6.1	6.4	14	11.9	12.0	24	22.2	21.5
−5	3.1	3.5	5	6.5	6.8	15	12.7	12.8	25	23.6	22.9
−4	3.3	3.8	6	7.0	7.3	16	13.5	13.6	26	25.0	24.2
−3	3.6	4.1	7	7.5	7.7	17	14.4	14.5	27	26.5	25.6
−2	3.9	4.4	8	8.0	8.1	18	15.4	15.1	28	28.1	27.0
−1	4.2	4.6	9	8.5	8.8	19	16.3	16.2	29	29.8	28.6
0	4.6	4.9	10	9.1	9.4	20	17.4	17.2	30	31.6	30.1

TABLE 26.—BOILING TEMPERATURE t OF WATER AT A PRESSURE OF a ATMOSPHERES. (Regnault)

t	a	t	a
100°C.	1.000	180°C.	9.929
121	2.025	189	12.125
134	3.008	199	15.062
144	4.000	213	19.997
152	4.971	225	25.125
159	5.966	239	27.534
171	8.036		

Table 27.—Coefficients of Linear Expansion for 1°C. (Kohlrausch)

Aluminum	0.000023	Lead	0.000029
Brass	0.000019	Platinum	0.000009
Copper	0.000017	Silver	0.000019
German silver	0.000018	Tin	0.000023
Glass	0.0000085	Wood with the grain	0.000003–10
Gold	0.000015	Zinc	0.000029
Iron	0.000012		

Table 28.—Coefficients of Cubical Expansion of Some Solids. (Everett)

Brass	0.000053–56	Platinum	0.000026–29
Copper	0.000052–57	Silver	0.000057–64
Glass	0.000023–28	Steel	0.000032–42
Iron	0.000035–44	Tin	0.000058–69
Lead	0.000084–89	Zinc	0.000087–90

Table 29.—Specific Heat of Some Bodies, referred to Water

Solids

Aluminum	0.2185	Iron	0.1125
Antimony	0.0507	Lead	0.0315
Bismuth	0.0305	Nickel	0.1100
Brass	0.0940	Platinum	0.0320
Copper	0.0933	Quartz	0.1910
German silver	0.0946	Silver	0.0559
Glass	0.1900	Tin	0.0559
Gold	0.0320	Zinc	0.0935
Ice	0.5040		

Liquids

Alcohol at 17°C	0.580	Glycerin at 0°–100°C	0.555
Carbon disulphide at 15°C	0.230	Mercury at 15°C	0.033
Chloroform at 15°C	0.233	Turpentine at 17°C	0.430
Ether at 15°C	0.530	Water	1.000

Gases at Constant Pressure (by Weight)

Air	0.2375	Oxygen	0.2175
Hydrogen	3.4090	Steam	0.4805
Nitrogen	0.2438		

TABLE 30.—VELOCITY OF SOUND PER SECOND IN SOME BODIES

	Meters		Meters
Air at 0°C.	332	Maple	4,100
Brass at 17°C.	3,500	Oak	3,800
Copper at 17°C.	3,700	Pine	3,300
Glass at 17°C.	5,000	Steel at 17°C.	5,100
Iron at 17°C.	5,000	Water at 8.1°C.	1,435
Lead at 17°C.	1,300		

TABLE 31.—MEAN INDEX OF REFRACTION, AND DISPERSION OF SOME BODIES

	Index of refraction	Dispersion	Reciprocal of the index of refraction
Air	1.000294		0.999
Alcohol	1.372	0.0133	0.729
Canada balsam	1.540		0.649
Carbon disulphide	1.680	0.5950	
Diamond	2.470	0.0837	0.405
Ether	1.360	0.7350	
Glass, crown	1.530	0.0220	0.654
Glass, flint	1.600	0.0420	0.625
Ice	1.310		0.763
Turpentine	1.480	0.6750	
Water	1.336	0.0132	0.748